DRA

(NASA-CR-148501) SEASAT ECONOMIC ASSESSMENT. VOLUME 8: OCEAN FISHING CASE STUDY Final Report, Feb. 1974 - Aug. 1975 (ECON, Inc., Princeton, N.J.) 131 p HC $6.00 CSCL 05C G3/43

N76-28621

Unclas 15363

VOLUME VIII

SEASAT ECONOMIC ASSESSMENT

OCEAN FISHING CASE STUDY

ECON INCORPORATED

Report No. 75-125-8A
NINE HUNDRED STATE ROAD
PRINCETON, NEW JERSEY 08540
609 924-8778

FINAL

VOLUME VIII

SEASAT ECONOMIC ASSESSMENT

OCEAN FISHING CASE STUDY

Prepared for

National Aeronautics and Space Administration
The Office of Applications
Special Programs Division
Washington, D.C.

Contract No. NASW-2558

October 1975

NOTE OF TRANSMITTAL

The SEASAT Economic Assessment was performed for the Special Programs Division, Office of Applications, National Aeronautics and Space Administration under contract NASW-2558. The work described in this report began in February 1974 and was completed in August 1975.

The economic studies were performed by a team consisting of Battelle Memorial Institute, the Canada Centre for Remote Sensing, ECON, Inc., the Jet Propulsion Laboratory and Ocean Data Systems, Inc. ECON, Inc. was responsible for the planning and management of the economic studies and for the development of the models used in the generalization of the results.

This volume presents the results of case studies and their generalization concerning the economic benefits of the data that could be provided by an operational SEASAT system to the ocean fishing industry. Areas investigated in the study include the use of improved ocean condition and weather forecasts to reduce weather induced losses to the fishing industry and the possibility of using data supplied by SEASAT to aid in the management of fisheries operations by improving fisheries populations forecasts.

The case studies were performed by the Canada Centre for Remote Sensing and the Jet Propulsion Laboratory. Mr. Robert Nagler managed the study performed by JPL. Prof. Donald Clough and Dr. Arch McQuillan performed the case study for the Canada Centre for Remote Sensing. Dr. William Steele of ECON, Inc. integrated the case study results and performed the generalization.

The SEASAT Users Working Group (now Ocean Dynamics Subcommittee) chaired by Dr. John Apel of the National Oceanographic and Atmospheric Administration, served as a valuable source of information and as a forum for the reviews of these studies. Mr. S.W. McCandless, the SEASAT Program Manager, coordinated the activities of the many organizations that participated in these studies into the effective team that obtained the results described in this report.

BPMiller

B.P. Miller

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES
(continued)

1. OVERVIEW OF THE ASSESSMENT

This report, consisting of ten volumes, represents the results of the SEASAT Economic Assessment, as completed through August 31, 1975. The individual volumes in this report are:

- Volume I - Summary and Conclusions
- Volume II - The SEASAT System Description and Performance
- Volume III - Offshore Oil and Natural Gas Industry - Case Study and Generalization
- Volume IV - Ocean Mining - Case Study and Generalization
- Volume V - Coastal Zones - Case Study and Generalization
- Volume VI - Arctic Operations - Case Study and Generalization
- Volume VII - Marine Transportation - Case Study and Generalization
- Volume VIII - Ocean Fishing - Case Study and Generalization
- Volume IX - Ports and Harbors - Case Study and Generalization
- Volume X - A Program for the Evaluation of Operational SEASAT System Costs.

Each volume is self-contained and fully documents the results in the study area corresponding to the title. Table 1.1 describes the content of each volume to aid readers in the selection of material that is of specific interest.

The SEASAT Economic Assessment began during Fiscal Year 1975. The objectives of the preliminary economic assessment, conducted during Fiscal Year 1975, were to identify the uses and users of the data that could be produced by an operational SEASAT system and to provide preliminary estimates of the benefits produced by the applications of this

Table 1.1: Content and Organization of the Final Report

Volume No.	Title	Content
I	Summary and Conclusions	A summary of benefits and costs, and a statement of the major findings of the assessment.
II	The SEASAT System Description and Performance	A discussion of user requirements, and the system concepts to satisfy these requirements are presented along with a preliminary analysis of the costs of those systems. A description of the plan for the SEASAT data utility studies and a discussion of the preliminary results of the simulation experiments conducted with the objective of quantifying the effects of SEASAT data on numerical forecasting.
III	Offshore Oil and Natural Gas Industry-Case Study and Generalization	The results of case studies which investigate the effects of forecast accuracy on offshore operations in the North Sea, the Celtic Sea, and the Gulf of Mexico are reported. A methodology for generalizing the results to other geographic regions of offshore oil and natural gas exploration and development is described along with an estimate of the world-wide benefits.
IV	Ocean Mining - Case Study and Generalization	The results of a study of the weather sensitive features of the near shore and deep water ocean mining industries are described. Problems with the evaluation of economic benefits for the deep water ocean mining industry are attributed to the relative immaturity and highly proprietary nature of the industry.

Table 1.1: Content and Organization of the Final Report
(continued)

Volume No.	Title	Content
V	Coastal Zones - Case Study and Generalization	The study and generalization deal with the economic losses sustained in the U.S. coastal zones for the purpose of quantitatively establishing economic benefits as a consequence of improving the predictive quality of destructive phenomena in U.S. coastal zones. Improved prediction of hurricane landfall and improved experimental knowledge of hurricane seeding are discussed.
VI	Arctic Operations - Case Study and Generalization	The hypothetical development and transportation of Arctic oil and other resources by ice breaking super tanker to the continental East Coast are discussed. SEASAT data will contribute to a more effective transportation operation through the Arctic ice by reducing transportation costs as a consequence of reduced transit time per voyage.
VII	Marine Transportation-Case Study and Generalization	A discussion of the case studies of the potential use of SEASAT ocean condition data in the improved routing of dry cargo ships and tankers. Resulting forecasts could be useful in routing ships around storms, thereby reducing adverse weather damage, time loss, related operations costs, and occasional catastrophic losses.
VIII	Ocean Fishing - Case Study and Generalization	The potential application of SEASAT data with regard to ocean fisheries is discussed in this case study. Tracking fish populations, indirect assistance in forecasting expected populations and assistance to fishing fleets in avoiding costs incurred due to adverse weather through improved ocean conditions forecasts were investigated.
IX	Ports and Harbors - Case Study and Generalization	The case study and generalization quantify benefits made possible through improved weather forecasting resulting from the integration of SEASAT data into local weather forecasts. The major source of avoidable economic losses from inadequate weather forecasting data was shown to be dependent on local precipitation forecasting.
X	A Program for the Evaluation of Operational SEASAT System Costs	A discussion of the SATIL 2 Program which was developed to assist in the evaluation of the costs of operational SEASAT system alternatives. SATIL 2 enables the assessment of the effects of operational requirements, reliability, and time-phased costs of alternative approaches.

data.* The preliminary economic assessment identified large potential benefits from the use of SEASAT-produced data in the areas of Arctic operations, marine transportation, and offshore oil and natural gas exploration and development.

During Fiscal Year 1976, the effort was directed toward the confirmation of the benefit estimates in the three previously identified major areas of use of SEASAT data, as well as the estimation of benefits in additional application areas. The confirmation of the benefit estimates in the three major areas of application was accomplished by increasing both the extent of user involvement and the depth of each of the studies. Upon completion of this process of estimation, we have concluded that substantial, firm benefits from the use of operational SEASAT data can be obtained in areas that are extensions of current operations such as marine transportation and offshore oil and natural gas exploration and development. Very large potential benefits from the use of SEASAT data are possible in an area of operations that is now in the planning or conceptual stage, namely the transportation of oil, natural gas, and other resources by surface ship in the Arctic regions. In this case, the benefits are dependent upon the rate of development of the resources that are believed to be in the Arctic regions, and also dependent upon the choice of surface transportation over pipelines as the means of moving these resources to the lower

*SEASAT Economic Assessment, ECON, Inc., October 1974.

latitudes. Our studies have also identified that large potential benefits may be possible from the use of SEASAT data in support of ocean fishing operations. However, in this case, the size of the sustainable yield of the ocean remains an unanswered question; thus, a conservative viewpoint concerning the size of the benefit should be adopted until the process of biological replenishment is more completely understood.

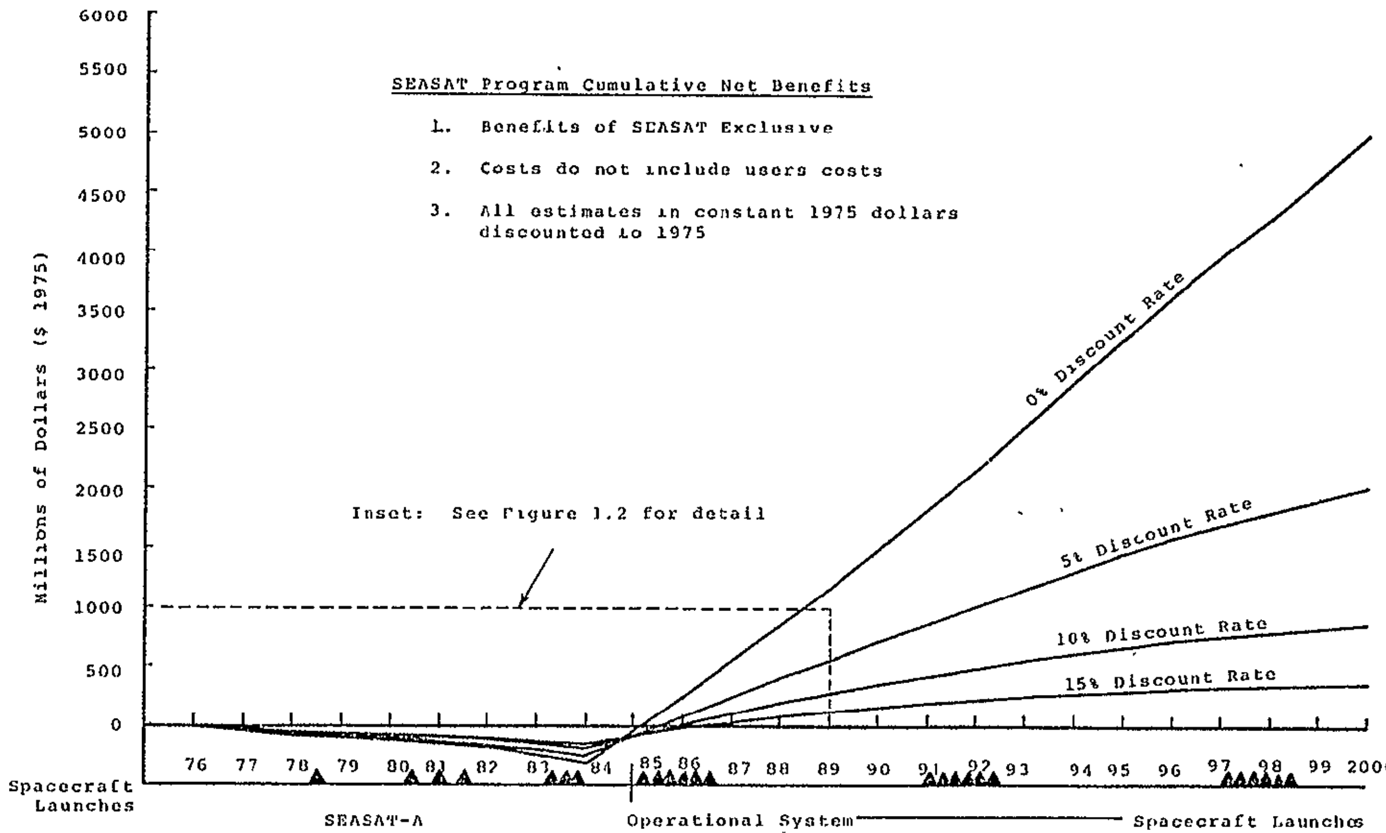
With the completion of this second year of the SEASAT Economic Assessment, we conclude that the cumulative gross benefits that may be obtained through the use of data from an operational SEASAT system, to provide improved ocean condition and weather forecasts is in the range of $859 million to $2,709 million ($1975 at a 10 percent discount rate) from civilian activities. These are gross benefits that are attributable exclusively to the use of SEASAT data products and do not include potential benefits from other possible sources of weather and ocean forecasting that may occur in the same period of time. The economic benefits to U.S. military activities from an operational SEASAT system are not included in these estimates. A separate study of U.S. Navy applications has been conducted under the sponsorship of the Navy Environmental Remote Sensing Coordinating and Advisory Committee. The purpose of this Navy study was to determine the stringency of satellite oceanographic measurements necessary to achieve improvements in

military mission effectiveness in areas where benefits are known to exist.* It is currently planned that the Navy will use SEASAT-A data to quantify benefits in military applications areas. A one-time military benefit of approximately $30 million will be obtained by SEASAT-A, by providing a measurement capability in support of the Department of Defense Mapping, Charting and Geodesy Program.

Preliminary estimates have been made of the costs of an operational SEASAT program that would be capable of producing the data needed to obtain these benefits. The hypothetical operational program used to model the costs of an operational SEASAT system includes SEASAT-A, followed by a number of developmental and operational demonstration flights, with full operational capability commencing in 1985. The cost of the operational SEASAT system through 2000 is estimated to be about $753 million ($1975, 0 percent discount rate) which is the equivalent of $272 million ($1975) at a 10 percent discount rate. It should be noted that this cost does not include the costs of the program's unique ground data handling equipment needed to process, disseminate or utilize the information produced from SEASAT data. Figures 1.1 and 1.2 illustrate the net cumulative SEASAT exclusive benefit stream (benefits less costs) as a

---

* "Specifications of Stringency of Satellite Oceanographic Measurements for Improvement of Navy Mission Effectiveness." (Draft Report.) Navy Remote Sensing Coordinating and Advisory Committee, May 1975.



Costs*	19	49	78	100	123	151	184	239	307	352	368	373	375	393	437	503	546	566	568	587	629	695	738	753
Benefits*										311	622	933	1244	1555	1937	2319	2701	3083	3465	384	4229	4611	537	5757

*Cumulative Costs and Benefits at 0% Discount Rate (millions, $ 1975)

Figure 1.1 SEASAT Net Benefits, 1975-2000

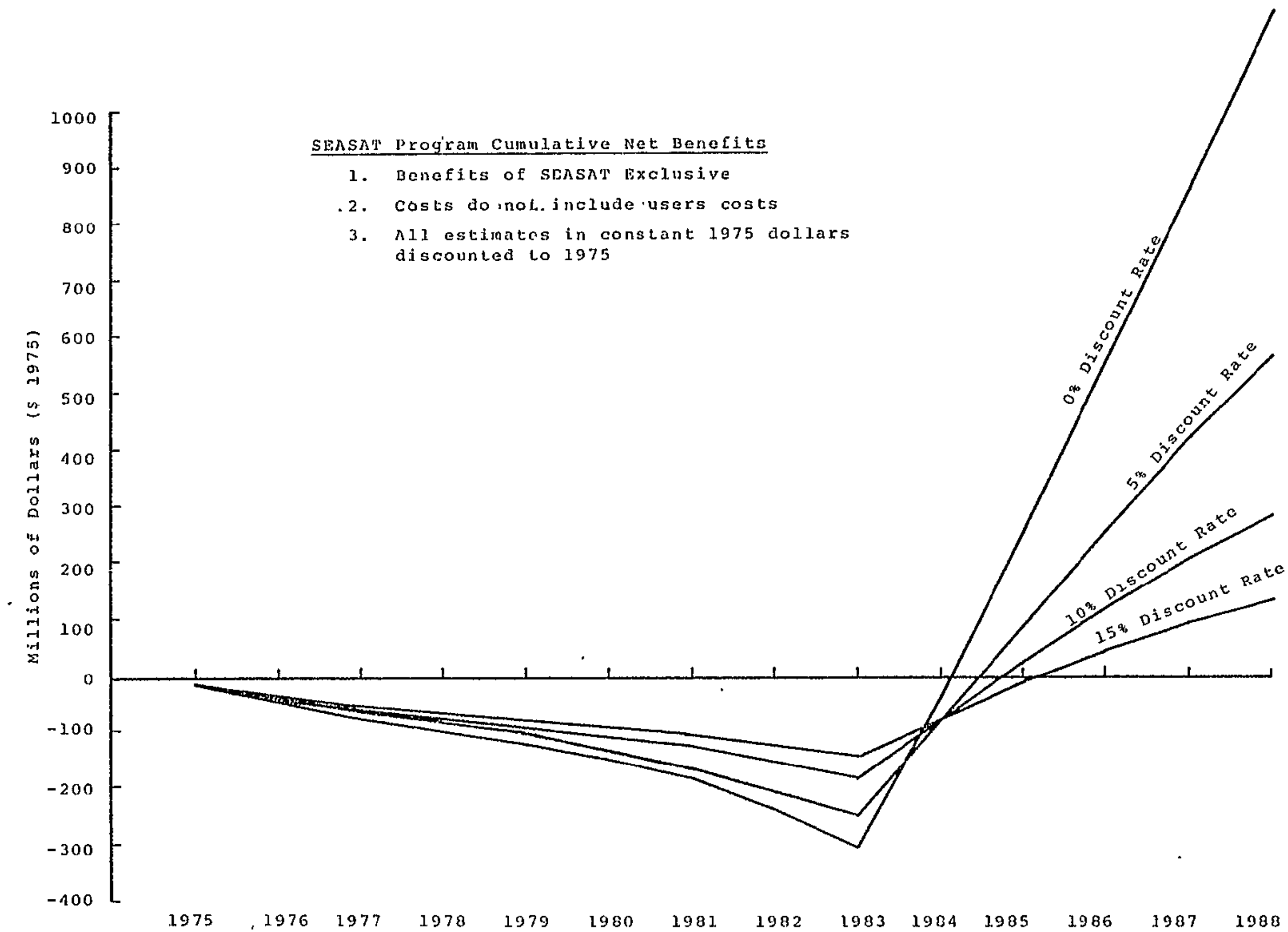


Figure 1.2 SEASAT Net Benefits, Inset

function of the discount rate.

This volume presents the results of case studies and their generalization concerning the economic benefits of the data that could be provided by an operational SEASAT system to the ocean fishing industry.

2. INTRODUCTION TO OCEAN FISHING CASE STUDY

The purpose of this study is to survey the various elements of the United States, Canadian and world commercial fishing industry in order to provide an estimate of the potential economic benefits that might accrue as a result of an operational SEASAT system. The various elements or applications surveyed were:

1. Improving fisheries population forecasts to aid fisheries management operations
2. Direct tracking of fish populations
3. Improving ocean condition forecasts to aid the United States fishing fleet.

Towards this end, Chapter 4 examines the potential use of SEASAT data in an ocean biological production simulator, a mathematical model which can forecast fisheries population. The model is first explained in Section 4.2, followed by a discussion in Section 4.3 of how the simulator may be applied to the eastern pacific tuna fisheries. Given various assumptions on improvements in fishery operational efficiency, including the possibility of improved fishery population forecasts, Chapter 6 examines the potential SEASAT benefits to the Canadian fishing industry. Possible operational efficiency improvements are set at 1 and 4 percent and the benefits are calculated for the time horizon 1985 to 2000, under various learning curve assumptions. Chapter 7, using the Canadian

results and assumptions, studies the potential benefits to the United States and world fishing industries for the years 1985 to 2000.

The extrapolation is accomplished under various assumptions on projected yields, consumption, species availability and relative prices.

The second major area of this report, direct tracking of fish population, is covered in Chapter 5, Section 5.3. Five separate fisheries, shrimp, salmon, tuna, menhaden and atlantic ground fish were selected for study using criteria of dollar size, landing tonnage and geographical location.

The final area to be studied, improving ocean condition forecasts to aid the United States fishing fleet, will be found in Chapter 5, Section 5.4. The three weather sensitive aspects of the fishing industry studied were reduction in weather-related cargo, vessel and human casualties, reduction in weather-related operational losses and reduction in hull insurance premiums.

3. SUMMARY OF RESULTS

This study analyzes the potential application of SEASAT data by the ocean fishing industry. The possibility of using operational SEASAT data to directly track fish population, to indirectly assist in the forecast of expected population, and to assist fishing fleets to avoid the costs incurred due to adverse weather through improved ocean condition forecasts were investigated. The following results were arrived at:

- Direct tracking of fish populations was determined not to be feasible and no benefits may be attributable to SEASAT in this area
- Improved ocean condition forecasts can aid United States fishing fleet ships avoid adverse weather-related costs. Incremental benefits due to use of SEASAT data in this application would be approximately $11.7 million undiscounted United States dollars in 1985. Cumulative discounted benefits, 1985-2000, would be approximately $40.4 million United States dollars
- Improved fisheries population forecasts can improve fisheries management operations. Incremental undiscounted benefits due to the use of SEASAT data in this application would be: for the United States, 3.4 to 14.9 million United States dollars in 1985; for Canada, 0.72 to 3.13 million dollars in 1985; for the world, 31.4 to 136.1 million United States dollars in 1985. The corresponding cumulative discounted benefits, 1985-2000, would be: for the United States, 30.2 to 157.9 million United States dollars; for Canada, 7.3 to 38.9 million United States dollars; and for the world, 274 to 1,432 million United States dollars.

All dollar figures above are in 1975 dollars. The discount rate used was 10 percent. The above results are summarized in Table 3.1.

Table 3.1 Summary of Overall Benefits, Marine Fisheries
(in million U.S. 1975 dollars)

	1985 Undiscounted Benefits	1985-2000 Cumulative Discounted Benefits*
I. Fisheries Population Estimation		
U.S. Benefits	3.4 to 14.9	30.2 to 157.9
Canadian Benefits	.72 to 3.13	7.3 to 38.9
World Benefits	31.4 to 136.1	274 to 1432
II. Avoidance of Adverse Weather Costs		
U.S. Benefits	11.7	40.4

*Discount Rate = 10%.

function of the discount rate.

This volume presents the results of case studies and their generalization concerning the economic benefits of the data that could be provided by an operational SEASAT system to the ocean fishing industry.

4. POTENTIAL USE OF SEASAT DATA IN AN OCEAN BIOLOGICAL PRODUCTION SIMULATOR

4.1 Introduction

The following discussion will describe in preliminary terms, a system whereby SEASAT data can be utilized to drive dynamic simulation models (called the Oceanic Biological Production Simulator) which will predict harvestable resource potential for major ocean regions. SEASAT will be seen as a realistic near-term data source for such models; however, much remains to be learned and accomplished. The currently available models and those which need to be synthesized will be enumerated; institutional considerations to institute management based on these models will be presented. Finally, the potential benefits to an exemplary fishery, the tropical tuna fishery, will be explored.

4.2 Explanation of the Oceanic Biological Simulator

4.2.1 Physical Subsystem

Two major factors controlling ocean production are the amount of solar radiation penetrating the ocean surface and the rate of supply of inorganic nutrients. The aim of the Physical Sybsystem is, therefore, to calculate in a spatial and temporal domain the solar radiation penetrating the ocean's surface and the amount and duration of upwelling of nutrient rich waters. The succinctness of the statement of the problem fails to reveal its complexity. The complexity of the calculation models is due to the many ocean-surface

and atmospheric factors involved, to their less than well understood effects upon the solar radiation ultimately absorbed by the ocean, and the amount and duration of up-welling.

In this section we shall review those atmospheric and surface factors controlling solar radiation and upwell-ing, examine them in some detail, and present means of cal-culating them within the proposed Physical Subsystem.

The data base for the proposed Subsystem can be gathered from the SEASAT satellite system, from meteorolog-ical satellites, and from conventional observations (ship reports, weather charts, etc.).

The SEASAT operational satellite system will pro-vide both dynamic data from which upwelling indices can be calculated and observational data from which upwelling events can be verified. The dynamic information will be in the form of sea surface roughness and foam cover from which wind speed and direction can be derived. The observational information will consist of sea surface temperatures and radar images, both of which will indicate upwelling boundaries.

Meteorological satellites of the GOES and NOAA series will provide cloud cover and type information for solar radiation calculations, and sea surface temperatures.

Conventional observations such as ship reports, weather charts, etc. can provide "ground truth" checks to satellite derived information, especially wind direction.

The interrelationships between data sources, measured phenomena, and inferred phenomena as treated by the Physical Subsystem are presented schematically in Figure 4.1.

The amount of solar radiation absorbed by the ocean, Sa, is that fraction of the total solar radiation, S_T, impinging upon the ocean's surface which is neither reflected nor back-scattered into the atmosphere. Thus the absorbed radiation is a function of the absorptance, α, of the ocean, or in equation rotation

$$Sa = \alpha \, S_T$$

Calculations of the Solar Radiation absorbed by the ocean, Sa, depend on the definition, an area of interest, of certain atmospheric and surface parameters, and the geometrical relationships between the sun and the ocean surface. The equation previously presented, modified for cloud cover conditions, becomes,

$$Sa = \alpha \, S_T F_S$$

where F_s is the solar radiation cloud factor which varies for cloud type and amount. Values of F_s are calculated from transmission values of solar radiation through clouds given in Smithsonian Meteorological Tables [4.9]. S_T, the total incoming clear-sky solar radiation, is the sum of direct clear-sky solar radiation at the ocean's surface $S_{(direct)}$, and the diffuse solar radiation, $S_{(diffuse)}$:

$$S_T = S_{(direct)} + S_{(diffuse)}$$

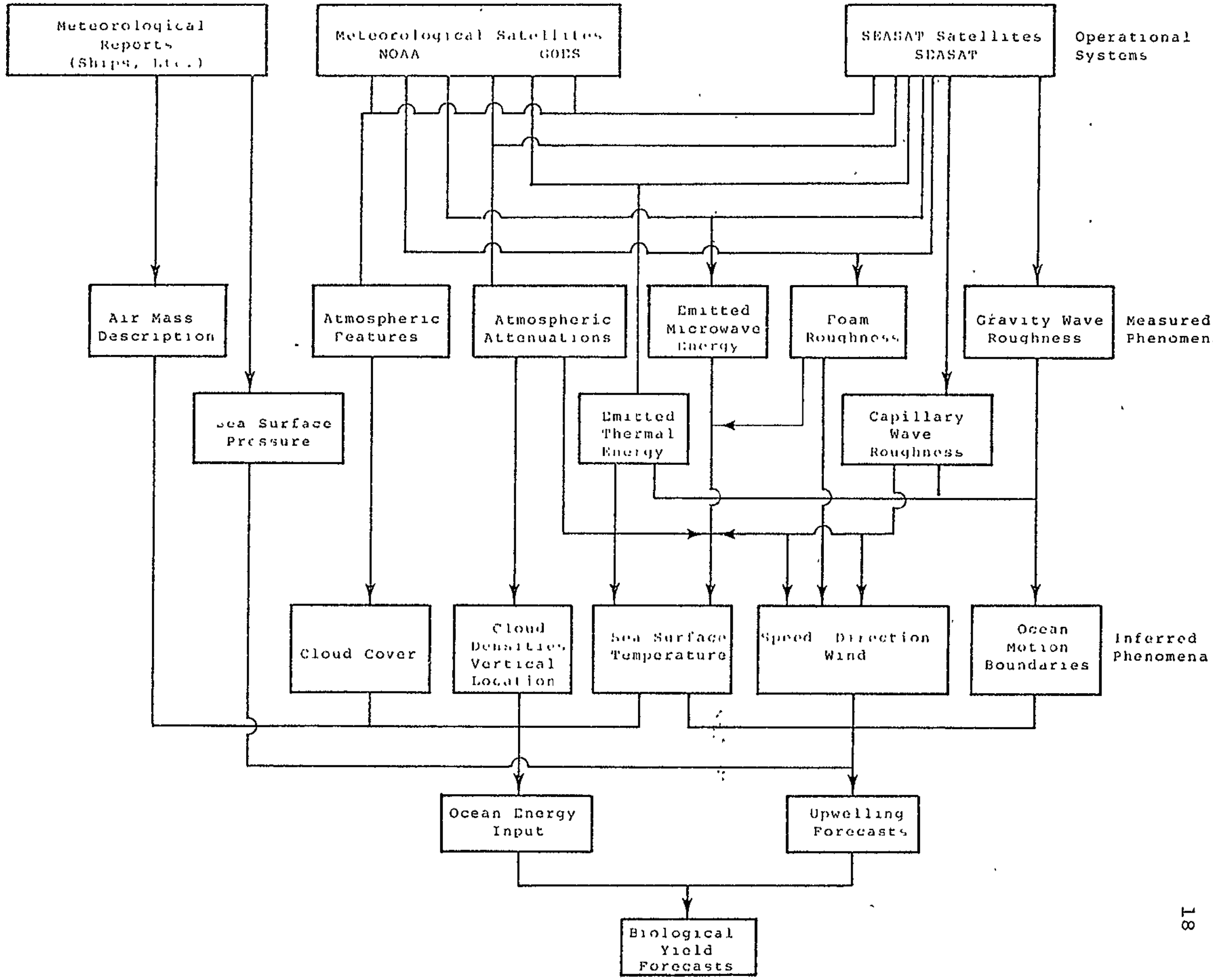


Figure 4.1 Biological Yield Forecast Procedure

The direct solar radiation is calculated by

$$S_{(direct)} = \int J_0 \cos z \tau^{\sec z} dt$$

where J_0 is the solar constant (2 cal/cm^2/min), z is solar zenith angle, τ is atmospheric transmission coefficient, and t is the integration time.

The diffuse solar radiation at the earth's surface $S_{(diffuse)}$, is estimated by the method presented in the Smithsonian Meteorological Tables [1-9] by,

$$S_{(diffuse)} = \frac{0.91\ S_0 + S_{(direct)}}{2}$$

where S_0, the incoming solar radiation at the top of the atmosphere is

$$S = \int J_0 \cos z\ dt$$

The solar zenith angle z, is a function of latitude, longitude, and time of day, and is calculated according to formulas given in SMT [4-9, p. 497]. The atmospheric transmission coefficient, τ, is calculated using a relationship developed by McDonald which involves atmospheric precipitable water (μ), and depletion, d, due to dust:

$$\tau = (1.00 - d) - 0.077\mu 0.3$$

The atmospheric water vapor, μ (cm. of precipitable water), is estimated from a knowledge of the air mass or from the surface vapor pressure, e_a, by:

$$\log_{10}\mu = -0.579 + 0.247 \sqrt{e_a}$$

Satellite images over the area of interest provide the cloud cover and type information for input to the Physical Subsystem. The images are visually analyzed for cloud cover and type and this data is encoded and punched on computer cards to form the Cloud Cover Field. Seven Types of clouds and their amounts are identified from the visible images. This analysis defines "polygons" of uniform or nearly uniform cloud cover and type by the latitude-longitudes of their perimeters. The polygon boundaries are encoded with the cloud cover and type information, which is then made available for solar radiation calculations.

What remains then is an estimate of the fraction of the total incoming solar radiation which is actually absorbed by the ocean surface, or the absorptance, α, of the ocean. The absorptance of a surface is related to the albedo (or reflectance), a, by

$$\alpha + a = 1 .$$

The ocean surface can be considered to be of infinitesimal thickness where all the energy that does not go through (is not transmitted to the lower layers) is reflected back to the atmosphere.

The calculation of ocean albedo (or reflectance) is quite a complex problem involving the interrelation of many factors as Figure 1 schematically indicates. A major effort in the further development of the Physical Subsystem is to better define the albedo of the ocean as a function of the geom-

etry, sea state, atmospheric conditions, and the production of the ocean itself, which influences the albedo through changes in backscattering.

Upwelling is the major process by which nutrient rich deep waters are entrained in the illuminated surface layers where they are available for production, and for providing virgin water which is sufficiently free from predators to allow accumulation of large phytoplankton blooms:*

A measure of the upwelling, both in its time duration and mass of water involved, is therefore a critical parameter for any biological model aimed at calculating ocean production. Coastal upwelling is largely due to replacement from below of surface water transported offshore by the stress of the wind on the sea surface. Therefore, the principal meteorological measurement used for calculating upwelling is wind speed and direction.

According to a theory developed by Ekman in 1905 and still widely accepted, the mass transport M is directed 90 degrees to the right (in the Northern Hemisphere) of the direction toward which the wind is blowing, and is related to the magnitude of the wind stress τ by

$$M = \tau/f$$

where f is the Coriolis parameter.

---

*See Cushing [4-6].

The sea surface stress is computed by means of the formula

$$\vec{\tau} = \rho_a C_d \left|\vec{v}\right| \vec{v}$$

where $\vec{\tau}$ is the stress vector perpendicular to the coast, ρ_a is the density of air, C_d is an empirical drag coefficient (0.0013), and $\vec{v}$ is the wind vector.

These equations and a knowledge of the wind is all that is required to calculate mean transport, M, or upwelling, for any ocean area. The accumulated upwelling index is simply a summation of M for each area from some starting date. The starting date may be the start of the "upwelling season" for the area under study, or simply the start of an upwelling event.

The above model of upwelling calculations has been used to calculate coastal upwelling indices near the west coast of North America (Bakun [4-2]) and, provided wind data are available, is readily amenable to the shorter time scales and smaller areas proposed in the physical models.

The concept of areal analysis used in the cloud cover analysis is also applicable here, in the calculations of upwelling, where wind speed and direction may be constant for a large area. The wind speed and direction will be derived from the microwave sensors and scatterometers on the planned SEASAT satellites, and be available, presumably mapped, or in some computer compatible form.

4.2.2 Biological Subsystem

The several components contributing to the biological segment of the numerical simulation can be considered as belonging to one of two groups, namely:

- Production
- Trophic Transfer.

The former consider the photosynthetic conversion of the energy in the downwelling irradiance into biochemical energy in the planktonic plant community. As in terrestrial systems, the production can be simplistically viewed as controlled by limiting functions. In the oceanic case the limit is generally nutrients and typically nitrogen. The exception occurs in the biologically most important ocean regions where nutrient rich deeper water upwells to the surface. In this circumstance, it is probable that light may become the principal limiting function. Thus, the production segment, considered in first approximation for the upwelling regions only, reduces to a two-component system; one simulating nutrient supply, the other light availability.

In an upwelling situation, the newly surfaced water is essentially devoid of plant plankton (phytoplankton). As the single celled phytoplankton seed into the new water and grow, they find essentially unlimited nutrients, at least in the initial growth stage. This portion of their growth simulation would follow a light limited function. As the water

mass continues to advect from the area of upwelling, the phytoplankton grow and deplete the entrained nutrients; at this point their growth becomes nutrient limited, hence the simulation must shift from an emphasis on light limitation to one of nutrient limitation.

Upon simulation of total organic production at the first trophic level, which represents the total, theoretical organic harvest available from the sea, the next problem becomes simulation of transfer of this production to a trophic level (organism assemblage) harvested (or harvestable) by man. This latter, which is perhaps most complex and least understood, is the trophic transfer segment.

The two principal components of the biological segment deal with the simulation of phytoplankton production under conditions of light-limitation or nutrient limitation. As a first approximation, this simplistic approach assumes that only one factor at any given time limits production. It is likely that this condition can be met by a single set of parameters combined into one differential equation. The transition from a condition of light limitation to one of nutrient limitation is achieved by changing the sensitivity of the simulator to the relevant parameters. It is recognized, however, that as the model develops it may be necessary to discard this simplistic approach.

The development of simulation techniques for phytoplankton production in the open ocean has become increasingly

sophisticated in recent years. Some of the models necessary for implementation of the system described herein are well developed, others have only been generally described. In the following paragraphs, the level of development of the two general areas encompassed in the production segment (light and nutrients) will be reviewed.

The earliest attempts at simulation of phytoplankton production as an alternative to the available, but time-consuming, techniques for directly measuring this quantity involved numerically describing the relationship between available light and chlorophyll--a concentration. This technique, proposed in 1956 by Ryther and Yentsch, assumed a constant relationship between chlorophyll content of cells and rate of CO_2 fixation. The simulation (although it was not then considered a simulation technique) was of the following form:

$$P = 3.7 \frac{R}{k} C$$

where

- P = phytoplankton production
- R = relative photosynthesis at ambient surface light intensity (determined empirically)
- k = extinction coefficient
- C = chlorophyll concentration

The major discrepency in this technique involved choice of the "assimilation factor," given as 3.7 in the original paper. This factor relates chlorophyll to carbon assimilation and has been challenged repeatedly (Curl and Small [4-3]).

Nonetheless, the technique has merit in that it requires only knowledge of ambient light and chlorophyll concentration. (The latter can be sampled much more rapidly than productivity.)

Following this early attempt at partial simulation of phytoplankton production utilizing measurements of available light, little additional progress has been made in refining the light-limit aspect of primary production. Thus, this component of the biological segment will require considerable further effort. Utilizing the limiting factor approach, it is anticipated that simulation can be achieved without direct recourse to an estimation of chlorophyll content. Rather, an approach similar to that used in the nutrient-limit component, as discussed below, will be employed. This approach is to specify initial conditions, including phytoplankton population levels, consistent with the known average situation for the ecosystem to be simulated.

Perhaps the most exhaustive current treatment of nutrient limited production is that given by Walsh and Dugdale for the Peruvian Upwelling Ecosystem (Walsh and Dugdale [1-1]. In their approach, Walsh and Dugdale constructed a non-linear numerical simulation of the upwelling ecosystem which is directly applicable to the present argument. The simulation utilized calculates the standing crops of nutrients which is then utilized to calculate the standing crop of phytoplankton. In word form:

d nutrients/dt = - advection + diffusion - nutrient uptake + herbivore excretion

and

d phytoplankton/dt = - advection + diffusion + nutrient uptake - grazing - sinking

The model, in numerical form, adequately duplicates the real world situation. A second generation refinement is currently being presented (Walsh [4-1], in press).

For the purposes of this discussion, the important features of the Walsh/Dugdale model are that the advection term (upwelling) is estimated from wind stress. The advent of SEASAT should considerably improve the accuracy of this term. Secondly, it accounts, in part, for second trophic level production; thus, it offers an initial point for estimating energy flow to herbivores (second trophic level organisms) and carnivores (third or higher trophic level organisms).

The most difficult task, given current understanding of oceanic trophodynamics, will be to simulate the transfer of energy (harvestable organic matter) from the primary producers to the trophic level harvested (or harvestable) by man in any given oceanic region. Classic approaches to this problem have assumed a ten percent efficiency for energy transfer between trophic levels. In a recent review, Steele [1-4] points out the complexity of feeding behavior in marine predators (food webs) and hence the gross oversimplification implicit in an assumption of ten percent efficiency. More intensive analysis of individual biomes will be required to

reasonably define the trophic transfer simulations for any given fishing region. It should be noted in conclusion however, that this problem does simplify for many of the most productive fisheries such as the Peruvian Anchovetta, where the harvested species is herbivorous, feeding directly on the organisms of interest in the production simulation.

4.2.3 Subsystem Output and Management Implications

The system described is expected to yield spatially and temporally coherent estimates of the potential biological yield at the primary and specified, higher trophic levels.

Specifically, the system will function as shown in Figure 4.2. The components can be viewed separately for their general (SEASAT sensitive) inputs and outputs, as follows:

Subsystem	Component	SEASAT Dependent Input	Output
Physical	Ocean Albedo	Sea State; Foam Atmospheric Attenuation	Visible Spectrum Radiant Flux
	Sea Surface Advection	Wind Speed; Direction; Ocean Dynamics Boundaries	Mass Transport
Biological	Solar Radiation	Visible Spectrum Radiant Flux	Light Limited Production
	Upwelling Index	Mass Transport	Nutrient Limited Production

If coupled with evolving dynamic fisheries models, this output would describe type and space/time coordinates for

harvest of various commercial species. Otherwise, it is anticipated that one typical output would be charts depicting the distribution of biological productivity on a real-time or quasi real-time basis.

The real utility of these management information models cannot be realized until an international framework exists within which the information provided can be rationally acted upon. Presently, most open ocean fisheries are either unregulated, or the international commission created for their regulation functions very inefficiently, if at all.

The Oceanic Biological Production Simulator described in the preceding pages and Figure 4.2 is envisioned as being applicable primarily to open ocean fisheries, especially those which occur in or near regions of continuous or seasonal upwelling. As such, they generally describe fisheries which occur outside the national boundaries of individual countries. Thus, a management scheme for any such fishery requires international cooperation, and an international framework within which to construct the management scheme. The history of the exploitation of the oceans is presently at a point where critical decisions are necessary in order to maintain the continuity of the major food resources of the ocean. This is recognized in the convening by the United Nations of a Law of The Sea conference in an attempt to establish some rational approach to the organization and exploitation of oceanic resources, both living and non-living.

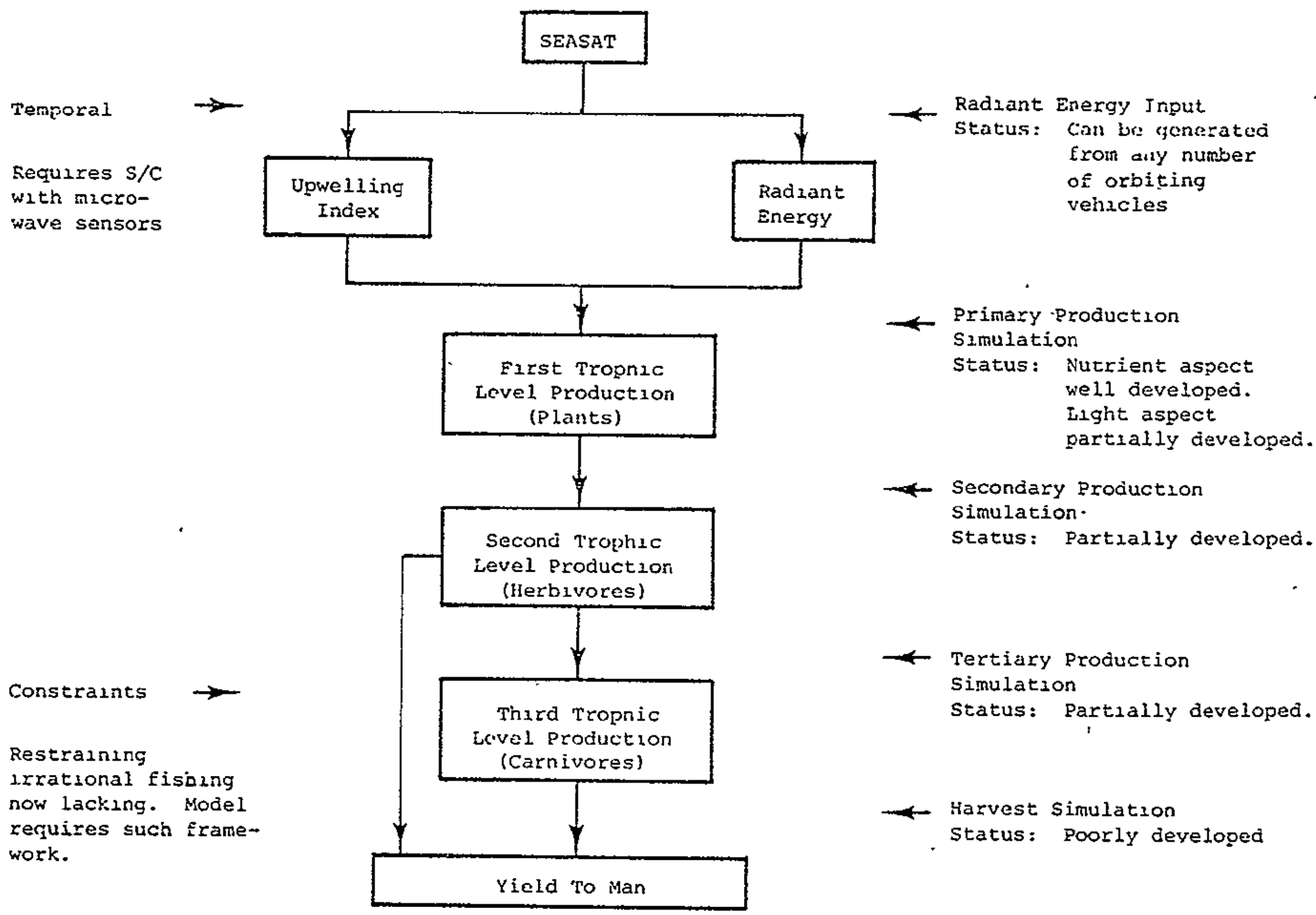


Figure 4.2 Oceanic Biological Production Simulator

For the living resources, the situation is complicated by the recent move by many national jurisdictions to extend their territorial sea to the 200-mile limit. If such a movement becomes popular, then the situation discussed will change and most of the fisheries of importance will fall within nationalistic boundaries. The resulting situation would probably be chaotic and counter-productive to rational management. Thus, the constraints considered are those which would occur through a rational international management scheme such as that which may occur as a result of the Law Of The Sea conventions. Given improved international relationships even a nationalistic approach to offshore resources may be compatible with rational species management of large oceanic fisheries.

A prerequisite for the management of oceanic fisheries is that they be approached from a species viewpoint. That is to say that each species or group of similar species exhibiting ecological interchangeability should be managed as a unit rather than having management authority rest with the coastal nation off whose shores the fishery occurs. In the latter instance, coordination over the geographic extent of a fishery, if it overlaps more than one national boundary, becomes extremely unwieldy. This particularly becomes the case with respect to a management scheme based on a SEASAT concept in that the large scale oceanic dynamic processes to be monitored and utilized really are not compatible with anything other than regional management criteria.

As common property resources, most offshore fisheries (i.e., outside nationalistic jurisdiction) are currently exploited on a first-come/first-served basis. This circumstance generally results in gross over-expansion of the fishing fleets involved, and a lack of any impetus for individual fishermen to practice conservation. Since there is no imposed limit and anyone can take whatever amount of fish he can catch, there is motivation for everyone to enter the fishery as an individual unit. This leads to a philosophy that anything left for tomorrow will be taken by someone else today; thus conservation becomes impractical.

Certain of the international offshore fisheries currently subscribe to some sort of international management program. An example to be further elaborated in the next section is the Inter-American Tropical Tuna Commission which oversees the eastern pacific yellowfin tuna fishery. Although this commission has a formalized quota system and is probably as well organized and managed as any international regulatory agency, it still leaves much to be desired. In this fishery a yearly quota is established. However, it is neither apportioned nor temporally spaced, so that where once the fishery lasted nearly an entire year, the carrying capacity of the present tuna fleet is such that for the year 1975 the carrying capacity on the day the season opened exceeded the quota for that year. In other words, after one trip by each vessel, the yearly quota would be reached. A rational fisheries approach

must allow for international management ascribed to by all fishing powers and apportioned fairly among these interests. Further, the fishing strategy must be such that some temporal constancy is imposed, decreasing the stress on the fishery and increasing the viability of the industry. This can only come about through the creation of management strategy dependent upon spatially/temporally coherent models. SEASAT represents a realistic source for the requisite physical data upon which such models will be built.

4.3 Potential Application of the Oceanic Biological Production Simulator to the Eastern Pacific Tuna Fishery

The U.S. Tropical tuna fishery extends nearly worldwide in the equatorial and near-equatorial seas. Of this region only the Indian Ocean is presently underexploited. Conversely, over all this vast ocean area, only one small segment is subject to an international management program. The Inter-American Tropical Tuna Commission (IATTC), established in 1949, and subsequently subscribed to by nearly all nations fishing the eastern Pacific for tuna, annually determines a quota for the yellowfin (Thunnus albacares) resource comprising the major portion of the annual harvest. The Commission, supported by its scientific staff, monitors the resource and the fishing pressure, thereby arriving at an approximate estimate of the yearly sustainable yellowfin yield. The quota, once established, is theoretically recognized by all member

nations; however, the U.S. fleet, with an aggregate carrying capacity estimated at 150,000 tons in 1974, represents the majority of the fishing potential.

Management of the eastern Pacific tuna fishery was undertaken when it became apparent that exploitation had a serious impact on the magnitude of the resource available, particularly for the more accessible and more lucrative yellowfin species. Skipjack (<u>Katsuwonus pelamis</u>) contributes a small fraction to the total harvest and is apparently unaffected by this level of exploitation. The significant impact of the fishery on the yellowfin resource led to the creation of a yellowfin regulatory area in 1966.

Regulation of the yellowfin fishery has been neither smooth nor precise. Management of the fishery was approached through the application of models which initially were structured on a classical Catch-per-Unit-Effort relationship. This approach, which is not temporally coherent, assumes Maximum Sustainable Yield to be the point beyond which increased effort (i.e., number of entrants) produces either no increase, or a decrease, in catch. More recently, dynamic fisheries models, accountable for age dependent differences in population, have been applied. These still, however, do not give adequate representation of the variability of the fishery.

The original management strategy utilized for the inter-American tropical tuna fishery did not account for age structure of the tuna population. Neither did it account for

the larger geographic distribution of the resource than that which was apparent during the more primitive days of the fishery. Thus, the quotas set on the basis of the early management models grossly underestimated the apparent availability of the resource.

In 1968, the IARRC undertook an experimental over-fishing program wherein an arbitrary quota was set and a close watch kept on the landings. With the advent of essentially unrestricted fishing even these generously estimated quotas were insufficient to account for the magnitude of fish taken. With the exception of 1971 (for reasons discussed later) the catch has increased yearly. In the last two years (1973-1974) age structure of the population has changed--a warning of potential overexploitation.

If the assumption is made that an Oceanic Biological Production Simulator such as that described above has application to a fishery such as the tropical tuna fisher, and that it can provide a more dynamic, realistic assessment of the available resource, then the potential benefits, in dollars, returned from the institution of such a management model can be assessed roughly in the context of three possible scenarios. These three scenarios describe the relationship between the suggested availability of the resource as determined by a given management scheme, and the actual availability as encountered by the fishing fleet. The scenarios are as follows.

1. Underforecast: wherein the absolute quota set by a regulatory commission grossly underestimates the true availability of the resource.
2. Overforecast: where the quota set by the regulatory commission grossly overestimates the resources.
3. Overexploitation: A continuation of the previous case to the point that the fishery is stressed for a period exceeding its flexibility and collapses.

Each of these will be briefly examined from a theoretical point of view. For the first scenario, one approach to estimating the potential dollar return from a more accurate forecast will be developed. For the second and third scenarios the difficulty of assessing the dollar impact except in the most preliminary sense will make it necessary to forego detailed economic analysis.

4.3.1 Underforecast

The underforecast scenario can best be developed by detailing the events over the past five years with respect to the yellowfin quota of the IATTC. In 1969 in response to the changes which had taken place in the fishery with the advent of a management program earlier in that decade, and with the unexpected changes in the index of yellowfin abundance as the fishery had expanded to the west and offshore, the IATTC began

an experimental overfishing program. On the basis of recommendations from the scientific staff the commission established a guideline for 1969, 1970 and 1971 of 120,000 tons of yellowfin. In both 1969 and 1970, the catch by the tuna fleet exceeded the quota set by the commission.

In 1970, a record 142,000 tons of yellowfin tuna were taken, with no indication that these landings were stressing the tuna population. In 1971 the quota of 120,000 tons was maintained, but in that year the commission left the option open for two incremental, 10,000 ton increases. However, in 1971 the total catch dropped to 114,000 tons. Again in 1972, the same quota and incremental system was established, and the unrestrained fishing resulted in a total yellowfin catch of 152,000 tons--an excess over the maximum expected quota of some 8.5 percent.

In 1973 the same situation prevailed. A quota of 160,000 tons was set, and the total yellowfin catch by the end of 1973 was 178,000 tons, an increase over the quota of over 11 percent. Total catch statistics for the year 1974 are not yet available, but the same situation appears to prevail. Now, however, the fishery is beginning to show signs of overfishing (as indicated by a shift in the age structure of the population) and it may be that the high quotas and unlimited fishing are beginning to deplete the available resource--a situation that only time will define.

For purposes of illustration, it is assumed that the fishery can sustain the level of fishing which has been exhibited in recent years and the Oceanic Biological Production Simulator will remove the variability in the present forecast system. On this basis, Table 4.1 presents the yellowfin catch for the years 1969-1973, the exvessel price, or "price to the fishermen," for this species, and the total boat value of the yellowfin catch for each of these years. Table 4.2 presents the dollar return for each of these years assuming that only the guideline quota had been captured. In Table 4.3 the actual dollar value of the catch, per year, is compared to the dollar value which would have accrued had only the quota limits been captured. It is evident from Table 4.3 that a significant gain to the fishery is possible provided that the higher fishing rates can be sustained and accurately forecast.

The significance of the information contained in Tables 4.1-4.3 to the present argument is that if the initial quotas had been strictly adhered to, as one assumes will be the case once the institutional constraints of a Law of the Sea convention are instituted, then an enormous dollar loss to the fishery would have accrued, assuming that the actual catch represents a sustainable harvest. With the exception of 1971, a year considered anomalous because of the effect on fishing strategy of the mercury scare and the high preponderance of skipjack, it can be seen from Table 4.3 that <u>the yellowfin catch was grossly underestimated for all years</u>. Further,

Table 4.1 Catch, Exvessel Price and Total Value
Yellowfin Tuna 1969-1973

Year	Catch+ (Thousands Of Tons)	Average Exvessel Price* ($/Ton)	Total Value (Millions of $)
1969	126	325	41.0
1970	142	367	52.1
1971	114	418	47.7
1972	152	442	67.2
1973	178	481	85.6

Table 4.2 Total Value of Quota Portion
for Each Year 1969-1970

Year	Initial Quota+ (Thousands Of Tons)	Average Exvessel Price* ($/Ton)	Total Value Of Quota (Millions of $)
1969	120	325	39.0
1970	120	367	44.0
1971	120	418	50.2
1972	120	442	53.0
1973	160	481	77.0

+ Source: Background Paper No. 2, 30th meeting, IATTC
* Source: NOAA/NMFS Food Fish Market Review and Outlook, November, 1974.

Table 4.3 Percent Variance of Dollar Return Between Actual and Recommended Yellowfin Tuna Catch* 1969-1973

Year Value (Millions of $)			Difference	
Year	Quota	Catch	In Dollars	By Percent
1969	39.0	41.0	+ 2.0	+ 5.1
1970	44.0	52.1	+ 8.1	+18.4
1971	50.2	47.7	- 2.5	- 5.0+
1972	53.0	67.2	+14.2	+26.8
1973	77.0	85.6	+ 8.6	+11.2

* Actual catch refers only to the area regulated by IATTC. Figures do not include value of yellowfin tuna taken outside the controlled area.

\+ 1971 is considered an anomolous year - see text for full explanation.

except in 1973, when the quota was finally raised in response to the previous years' increased catches, the difference between catch and quota steadily increased.

In considering the discrepancy between catch and quota, several points must be noted. Although the aggregate carrying capacity of the fleet increased from less than 70,000 to more than 150,000 tons during the period 1969 to 1973, this does not impact the biological aspects of the management quota. The net effect of increased carrying capacity has been to reduce the number of trips per boat necessary to reach a given catch level. Succinctly, increased carrying capacity has resulted in a decreased season. The present management system, although it utilizes age-dependent fisheries models, does not account for spatial-temporal variability in the resource or environment. The data in Tables 4.1-4.3 present arbitrarily variable data in the sense that the quota figures are really best guesses. The central point of the present argument is that the SEASAT-dependent system as envisioned herein will substantially reduce variability in management quotas.

4.3.2 Overforecast

The second scenario deals with the situation wherein a quota is set which cannot be realistically met. In this situation it is assumed that the fishermen accept the quota and commit a number of men and vessels concomitant with the forecast catch. In this event, the costs can be estimated on the

basis of the value of the ships committed, which could otherwise be fishing elsewhere, and the costs per day for operating such vessels. The most modern of the seining fleet average $2 million to $3 million in construction costs, and $1,000 to $1,500 per day to operate exclusive of crew costs. Thus an overcommitment of vessels decreases efficiency, increases the number of vessels which do not meet costs, and represents a net dollar loss to the industry. Such a situation may eventually lead to the demise of certain components of the fishery, or to distrust in the quota system on the part of the industry. Preventing the former has significant dollar benefits; the latter, if it contributed ultimately to the total decline of a fishery, is devastating in its economic and social impact.

4.3.3 Overexploitation

That a fishery can be totally destroyed from a commercial standpoint as the result of overfishing is dramatically illustrated by the decline and ultimate demise of the surface sardine fishery in Monterey Bay in the late 1940s and early 1950s. Nearly all of the fishery biologists who examined this situation attribute the decline almost exclusively to the result of overfishing. Biologically, the eastern Pacific tropical tuna fishery is analogous to the sardine fishery in sufficient sense to assume that overfishing can similarly destroy the yellowfin fraction of this fishery. In fact, accumulating biological evidence, including a radical change in the age structure of the population and a sharp drop in catch per unit effort, now in-

dicates that the current fishing level is exceeding the carrying capacity of the yellowfin population and that severe curtailment may be necessary. Again, assuming that a combined management program utilizing the Oceanic Biological Production Simulator discussed herein and the dynamic fisheries models currently being devised would be sufficient to adequately manage the yellowfin fishery, then the potential loss through inadvertent overfishing as a result of inadequate management models can be grossly addressed from a financial perspective. The total exvessel value, or "value to the fisherman" of the 1973 catch of yellowfin was $109.4 million. This value includes the yellowfin caught both in and out of the regulated area. If the fishery were destroyed, loss of this revenue would not be the sole economic impact. In addition to this loss, the loss at the wholesale and retail level of the yellowfin derived tuna pack would be very significant. Yellowfin are the main contributor to the light meat product which represents the majority of the domestic sales of canned tuna. Assuming that the yellowfin taken in the eastern Pacific represent half of the domestic canned lightmeat product, a conservative estimate, then the wholesale value of this fraction is $168 million based on a tuna pack in California and Puerto Rico (major ports for the yellowfin fleet) of 17,700,000 cases and an average wholesale price of $19.00 per case in 1973 (source: NOAA/NMFS Food Fish Market Review and Outlook, November 1974). The retail value of this fraction is even larger.

In conclusion, then, it can be seen even with this very preliminary analysis, that the proposed Oceanic Biological Production Simulator which could be made available from SEASAT, when combined with more conventional fishery management programs, can provide the framework wherein rational management of ocean fisheries will achieve a long-term sustained yield potential.

5. THE UNITED STATES FISHERIES CASE STUDY

5.1 Introduction

The purpose of this study was to survey various elements of the U.S. commercial marine fishing industry in order to provide an estimate of the potential economic benefits that might accrue as a result of an operational SEASAT system. The study had three parts:

1. An analysis of the potential effects of SEASAT data on production end of the U.S. commercial fishing industry
2. The performance of a case study evaluating the losses suffered by the U.S. fishing fleet due to sea damage
3. An analysis to assess the application of SEASAT data to an oceanic biological production simulator, and through the use of this model to estimate the benefits to the tropical tuna fishery.

In general, the case study approach consisted of:

1. Analyzing the selected system to define a set of activities with similar technical and operational characteristics
2. Identification of the systems major parameters and their estimated cost effect

3. Determination of the expected level of improvement assuming an operational SEASAT system
4. Estimation of the economic differential between present and improved operations.

The first part of the study focused on the U.S. marine commercial fishing industry to determine if an operational SEASAT could increase fishery production. The following criteria were used to select five major fisheries for evaluation:

1. The fishery had to represent a major economic input to the entire U.S. fishery
2. The selection had to include major fish types (e.g., demersal, ocean pelagic, anadromous)
3. The selection had to represent major U.S. fishery geographical areas.

Based on these criteria, Gulf shrimp, tuna, salmon and menhaden, the Atlantic Ground Fisheries were chosen. These fisheries produced approximately 60 percent of the total volume and 53 percent of the dollar value of all U.S. landings for 1973. The first order operational and technical characteristics of the fisheries were examined to determine in what way remote sensing could improve present operations with an end result of higher production and/or lower per unit costs.

On the basis of this study, it was concluded that the SEASAT could provide only limited assistance to the production end of the major U.S. fisheries. Of the fisheries surveyed, only tuna and menhadin had potential straightforward production

benefits. Increased U.S. production might occur; however, if underutilized species or new fishing grounds could be located. For example, the Gulf menhaden fishing grounds were developed in the 1950s and have produced millions of dollars in resource. Location of major and underutilized species as well as new grounds are within SEASAT's potential through indirect measurements or observations of surface modulations caused by large schools of top feeding fish, sea surface temperature and boundaries, thermocline depth, currents, upwellings, nutrient supply, fish oil identification, salinity and other environmental parameters. This is dealt with in later sections.

The main thrust of this section of the study deals with determining the primary causes of sea damage suffered by the marine fishing industry and estimating the potential level of improvement assuming highly reliable 48-hour weather prediction capability.

United States Coast Guard statistics were analyzed for fishing vessel casualties, cargo loss and death or injury. Operational data were used to project loss of resource and wages based on the estimated loss of productive fishing days due to adverse weather. Similar data were used to calculate loss of income to crew due to weather-related fatalities and injury. A correlative effort surveyed the ocean marine insurance field in an attempt to determine potential savings to fisherman based on reductions in hull premiums. The results of the sea damage case study are presented in Table 5.1.

Table 5.1 Annual Potential Benefits to U.S. Fisheries in Eight Areas

Type of Estimated Loss	Fraction of Industry Included	Estimated Dollar Value of Loss (Per Year)	Strengths of the Estimated Potential Benefits	Weaknesses of the Estimated Potential Benefits
Weather Casualties to Vessels & Cargo	Entire	$4,700,000	1. Based on Coast Guard data. 2. Categorized to isolate adverse weather effects.	1. Assumes only 30-40% of casualties reported. 2. Could include intentional losses. 3. Inability to quantify what percentage of losses would be prevented with functional SEASAT.
Weather Injury Losses (Cost for Injury)	Entire	$1,130,000	1. Data is consistent with fatality/injury ratios from other occupations. One can assume that since fishing is a high risk, high hazard industry, injury levels may be greater than reported here.	1. USCG injury statistics lacking due to insurance cost penalty. Data had to be derived from other sources.
Death (Life Coverage)	Entire	$ 520,000	1. Based on USCG data. Unlike vessel casualties, all deaths are reported. 2. Categorized to isolate adverse weather effects. 3. Overall losses are probably greater when one considers size of recent settlements above and beyond life insurance, e.g., negligence or unsafe vessel legal suits or out-of-court settlements with family of injured.	1. Inability to quantify exact percentage of deaths that could be prevented with functional SEASAT. 2. Assumes deceased fisherman holding private policies, either term or whole life.

Table 5.1 Annual Potential Benefits to U.S. Fisheries in Eight Areas (Continued)

Type of Estimated Loss	Fraction of Industry Included	Estimated Dollar Value of Loss (Per Year)	Strengths of the Estimated Potential Benefits	Weaknesses of the Estimated Potential Benefits
Loss of Resource (Productive Fishing Time)	50-60%	$ 678,000	1. Loss of days and affected fishery based on USCG data. 2. Categorized to isolate adverse weather effects. 3. Value of significantly higher since only 50-60% of U.S. fisheries are represented 4. Does not consider ex-vessel price increase trend.	1. Does not consider rapidly rising operating costs. 2. Distribution of lost days to representative fisheries was arbitrary.
Loss of Wages (Productive Fishing Time)	50-60%	$ 296,000	1. As above.	1. As above. 2. Figures are not additive (resource and wage loss) because in most fisheries wages are paid from resource take, On some vessels, however, all hands do not share in the take, but are paid a salary, e.g., cook. In these cases the loss is additive.
Loss of Earnings (Fatalities)	Entire	$ 228,000	1. Deaths based on USCG data.	1. Assumes that deceased men are not replaced during year following death. Replacement is delayed, however, as available experienced manpower pool has been decreasing in last few years. Experienced replacement adds to cost of vessel operation.

Table 5.1 Annual Potential Benefits to U.S. Fisheries in Eight Areas (Continued)

Type of Estimated Loss	Fraction of Industry Included	Estimated Dollar Value of Loss (Per Year)	Strengths of the Estimated Potential Benefits	Weaknesses of the Estimated Potential Benefits
Loss of Earnings (Fatalities)	Entire	$ 228,000	2. Categorized to isolate adverse weather effects. 3. Loss of dollar productivity to society is real.	2. Average replacement time of deceased men cannot be estimated. For shrimpers it is short duration; for North Atlantic it is much longer. 3. Distribution of deaths to representative fisheries was arbitrary.
Loss of Income (Injury)	Entire	$ 482,000	1. Loss of dollar productivity to society is real. 2. Injury incapacity estimate (3 days) was conservative. Average injury incapacitance for fishermen is 20-30 days.	1. USCG injury statistics lacking due to insurance cost penalties. Data had to be derived from other sources. 2. Under Maritime Laws & Jones Act, fishermen have certain entitlements including wages until end of voyage; however, payment is erratic and fishery specific. Under proposed Senate bill, injured fishermen would receive 50-60% of average daily wage or fishing share, whichever is lower.

Table 5.1 Annual Potential Benefits to U.S. Fisheries in Eight Areas (Continued)

Type of Estimated Loss	Fraction of Industry Included	Estimated Dollar Value of Loss (Per Year)	Strengths of the Estimated Potential Benefits	Weaknesses of the Estimated Potential Benefits
Reduction in Hull Premiums	Entire	$2,330,000	1. Variability of rates within geographical area suggests good possibility of standardization at lower rates, assuming casualty reductions in that area. 2. The proposed rate reductions for hull insurance were a result of a comprehensive study by USCG. This group included marine insurance representatives. 3. SEASAT could potentially affect 11 or 22 of the basic criteria used to set insurance rates; 6 directly and 5 indirectly. 4. The majority of hull marine insurance is written by only 5-7 companies; implementing new procedures to isolate SEASAT benefits is realistic. 5. Study does not consider potential saving associated with return of foreign writings to domestic market.	1. This is not a straight-through benefit to the fishermen, but is moderated through the insurance company. 2. Before benefits could be accrued by the fishing industry, insurance companies must begin to maintain causal statistics for FV casualties. 3. Insurance companies would require trend analysis before altering rates that are presently providing a profit. At present they would require a five-year trend. 4. The desire of insurance companies to build reserves against potential catastrophic losses would exert pressure on any rate reduction.
TOTAL		$10,073,848		

Briefly summarized, the estimated benefits that may accrue to the U.S. marine commercial fishing industry from improved weather and ocean condition forecasts approximates \$11 million per year. Interpretations of the strengths of the potential dollar benefits as well as circumstances which could mitigate the value are also listed in the table. No attempt was made to determine the ultimate recipient of the proposed benefit.

5.2 Summary of Case Study

Table 5.1 summarizes the potential benefits and assumptions in the case study.

5.3 Marine Fisheries; Production

The production case study examined five fisheries; shrimp, salmon, tuna, menhaden and Atlantic ground fish. For each species the current location techniques, harvest techniques and transport procedures were examined for possible remote sensing applicability. Out of these three processes, location of fish schools was thought to have the most promise with respect to remote sensing. This study concludes that since the remote sensing capability is functional only at the surface, the evaluation indicated that little or no assistance could be given to the production end of the major U.S. fisheries. A small amount of potential benefit might be found in tuna and menhaden school location and also in the location of entirely new fishing grounds.

In the latter case SEASAT could indirectly measure temperature, upwellings, nutrient supply and salinity.

In analyzing this conclusion there are perhaps two crucial areas that must be noted:

1. The criteria used to select the five representative fisheries
2. The reason in each fishery and direct use of remote sensing was found inapplicable.

The five fisheries were selected by the following criteria:

1. The fishery must represent a major economic input to the entire U.S. fishing industry.

   Rationale: If SEASAT could not assist major fisheries, its overall impact would be minimal.

2. The selection must represent major fishery types.

   Rationale: By assessing major types, e.g., demersal, ocean pelagic, coastal pelagic and anadromous, other applications may be made as necessary.

3. The fishery must represent major U.S. geographical areas.

   Rationale: By assessing fisheries that dwell in or move through major geographical areas, the spectra of problems presented by coastal or open ocean fishing can be addressed.

In Table 5.2, the attributes of each fishery are shown It can be seen that each meets the stated criteria. As to the second question of remote sensing applicability, the surface characteristics of each species were examined. The results are summarized for each fishery in the following paragraphs. It should be noted that only the direct applicability of remote sensing to production was examined. i.e., location of schools by direct observation. (See the Canadian study, Chapter 6, of this report for a discussion of indirect application of SEASAT.)

1. Shrimp

   Harvest forms (adults) are demersal with some minimal surface activity. Satellite detection and location impact minimal to nil.

2. Salmon

   Detection and location only a problem for trollers (which represent small percentage of production). Problem in this industry is balancing harvest so it is not total. No impact.

3. Tuna

   Harvest forms are pelagic but wide-ranging. Best potential is in high-paying albacore resource. Indirect assessment using temperature (fish migrate along specific isotherms) could be productive in early location and tracking.

Table 5.2 Selection of Major U.S. Fisheries (Data)

Fishery	Ecological Type	Geographic Area	Volume Landings Thousand Pounds*		$ Value Thousand Dollars	
			1972	1973	1972	1973
1. Gulf Shrimp(1)	Demersal Seasonal	Gulf of Mexico	228,488	182,069	163,417	172,961
2. Tuna	Ocean Pelagic Year Around	West Coast Am., Western Pacific, Offshore Central Pacific	377,569	342,091	89,993	90,105
3. Salmon	Anadromous Seasonal	California North To Bering Straits	216,685	213,009	62,758	125,113
4. Menhaden(2)	Coastal Pelagic Seasonal	Atlantic & Gulf	1,938,767	1,890,347	31,214	73,276
5. At Ground	Demersal Year Around	Western Atlantic	167,164	181,700	19,712	22,400
Totals - Five Selected Fisheries			2,928,673	2,809,216	367,094	483,855
U.S. Grand Total; All Fisheries			4,710,400	4,732,100	703,600	907,400

NOTES: (1) Gulf shrimp landings represented 49% of the U.S. landings and 79% of the total value.

(2) Gulf landings accounted for 1.1 billion pounds.

* Does not include landings by U.S. flag vessels at Puerto Rico or other ports outside continental U.S. and Hawaii.

4. Menhaden

   Harvest forms are pelagic and potential exists for an impact. However, satellite detection and location would be hard pressed to better present aircraft spotter techniques.

5. Atlantic ground fish

   Harvest forms are demersal and satellite impact would be nil. Even if detection could occur present grounds are under heavy pressure and quota controlled.

5.4 Marine Fisheries; Losses Due to Adverse Weather

As to the losses incurred by the commercial fishing industry due to weather, the study reviewed three areas where SEASAT could be helpful. These were:

1. Reduction in weather-related cargo, vessel and human casualties
2. Reduction in weather-related operational losses
3. Reduction in hull insurance premiums.

In each of these three areas it must be kept in mind that only the <u>potential</u> benefits that <u>could</u> accrue to the U.S. commercial fishing industry from remote sensing were examined.

In arriving at an annual loss of $6.352 million in the casualty area, the Coast Guard data on those accidents where weather was at least a contributing factor was reviewed first. For cargo and vessel damage the Coast Guard figures point to a

$1.590 million annual loss, where $1.476 million was due to cargo and hull damage and adverse weather was a primary cause (i.e., $52,000 + $1,424,000; see Table 5.3). The remaining $114,000 were due to losses where human error was the primary cause and weather the primary contributing factor ($3,000 + $111,000; see Table 5.4). Unfortunately, the total Coast Guard hull and cargo loss of $1.590 million annually is probably underestimated by a factor of 3. The reason for the underestimation is simply that many ship owners are unwilling to report minor accidents since upon report insurance premiums are likely to rise. Accordingly, the $1.590 million was multiplied by three to arrive at a $4.77 million total annual loss (or potential benefit). The remaining $1.582 million annual casualty loss was due to human casualties, where again relying on Coast Guard data, it was concluded that injury losses totaled $1.134 million and death losses totaled $520 thousand. The death loss figure was computed by taking an estimated 26 deaths (see Tables 5.3 and 5.4 20 crew deaths due to weather as a primary cause and six deaths out of 12 in Table 5.4 as resulting from weather as a secondary cause) caused by weather directly or indirectly and multiplying by $20,000, the value of an estimated life insurance policy. The injury loss figure covers only the medical expenses (average $341 per injury) for 3,328 weather-related injuries. The number of injuries is only an estimate,

Table 5.3 Average Annual U.S. Commercial Fishing Vessel Casualties
All Causes and Adverse Weather as Primary and Secondary Cause

	Total Number Of Incidents	Crew Deaths	Crew Injuries	Cargo Damage ($000)	Hull Damage ($000)
Average Annual Casualty Losses <u>All Primary Causes</u> for Period (1969 - 1974)	470	60	16	549	11,763
Average Annual Casualty Losses <u>Adverse Weather/Storms</u> <u>As Primary Cause</u> for Period (1969 - 1974)	62	20	<1	52	1,424
Average Annual Casualty Losses <u>Adverse Weather</u> <u>As Secondary Cause</u> for Period (1969 - 1974)	44	12	<1	55	1,160

Table 5.4 Casualties as a Result of Human Error as a Primary Cause and Weather as a Contributing Cause

Primary Cause Human Error Year	Crew Deaths	Weather Contributing Factor Crew Injuries	 Cargo Damage ($000)	 Hull Damage ($000)	Number Of Cases
1969	1	-	10	234	10
1970	2	-	4	147	5
1971	5	-	4	214	11
1972	5	-	-	55	5
1973	3	-	-	9	4
1974	2	-	-	4	2
TOTAL	18	-	18	663	37
AVERAGE PER YEAR	3	-	3	111	6

since again insurance considerations make the Coast Guard data conservative. As a result, it was assumed that on the average there are 128 injuries per death or 3,328 total weather-related injuries.*

For the operational losses incurred by adverse weather, it was concluded that for the five fisheries reviewed, a total of 1,059 days were lost due to adverse weather (see Table 5.5). Taking into account fishery and geographic wage differentials, and average value per day of catch, this weather-related loss in productive fishing time is worth $677,000 annually. (see Table 5.6). In each of these operational accidents, e.g., vessel damaged or nets lost, human error was the primary cause, but weather was a contributing factor. Of the $677,000 annual total, $296,000 represented lost crew wages. In the area of lost wages due to crew <u>injury</u> and <u>death</u>, (net of life insurance and medical expenses), the annual losses are $482,000 and $2.958 million respectively, again taking into account geographical and fishery wage differentials (see Tables 5.7 and 5.8).

In the final area, reduction in hull premiums, it was concluded that SEASAT could effect an annual potential savings of $2.3 million. To derive this benefit, the U.S. marine insurance industry was examined. Insurance premiums

---

*An Overview of Commercial Fishing Vessel Safety in the Northwest and Alternatives for Loss Prevention, NOAA Contract 03-4-208-00190, April 1974.

Table 5.5 Estimated Vessel Days Productive Fishing Time Lost Due to Casualties (Vessels 5 NT and Over, 1969-70)

Fishery	Total Days[1] Lost All Causes	Attributable to Casualties Caused By Adverse Weather/Storms (13.0% of Total)	Attributable to Casualties Caused By Human Error (Calculated Risk & Unsea) With Weather Contribution Facility (1.2% of Total)	Total Days Lost to Casualties (Weather Related)
At Ground Fish	618	80	7	87
Gulf Menhaden	6	.78	.07	1
Gulf Shrimp	5,148	670	62	732
Pacific NW Tuna Seiners	508	66	6	72
Pacific NW Salmon/Tuna Trollers	344	45	4	49
Pacific NW Salmon Gill Netters	536	70	6	76
Alaska Salmon Purse Seiners	295	38	4	42
TOTAL	7,455	970	89	1,059

(1) Planning Staff, Office of Merchant Marine Safety, "A Cost-Benefit Analysis of Alternative Safety Programs for U.S. Commercial Fishing Vessels (Part II) May 1970."

Table 5.6 Estimated Dollar Loss to Major Fisheries as a Result of Productive Fishing Time Lost Due to Casualties Caused by Adverse Weather (Average Per Year)

Fishery	Productive Vessel Fishing Days Lost (1)	Average Crew Member Income/Day ($)	Average Number of Crew	Crew Dollar Loss-Wages ($)	Average Resource Value Lost ($)
Atlantic Ground	87	Boston - 55 Bedford- 49	Boston - 16 Bedford- 5	Boston - 38,280 Bedford- 10,657 (43.5 days each)	Boston - 65,250 Bedford- 23,490 (43.5 days each)
Gulf Menhaden	1	45	12	540	2,500
Gulf Shrimp	732	43	4	125,904	275,232
Pacific NW Tuna Seiners	72	97	13	90,792	254,736
Pacific NW Salmon/Tuna	49	48 (2)	Tuna - 10 Salmon- 2	Tuna - 11,760 Salmon- 2,352 (24.5 days each)	Tuna - 15,950 Salmon- 3,920 (24.5 days each)
Pacific NW Salmon Gill Net	76	59	2	8,968	16,112 (3)
Alaska Salmon Purse Seiners	42	27	6	6,804	20,580
TOTAL				$296,057	$677,770

(1) Planning Staff, Office of Merchant Marine Safety "A Cost-Benefit Analysis of Alternative Safety Programs for U.S. Commercial Fishing Vessels (Part II) May 1970."

(2) Average of salmon troller ($65) and tuna troller ($30).

(3) Average resource value of Alaska ($244) and west coast ($180).

Table 5.7 Estimated Loss of Earnings to Fishing Industry Due to Fatalities Caused by Adverse Weather[1]

Area	Distribution of Deaths/Year by Geographic Area (Average)	Death Distribution By Fishery	Average Year Income Per Area Fishermen ($)	Estimated Loss of Income ($)[2]
Atlantic	4	2	Boston - 12,650	$ 328,900
		2	Bedford - 11,270	293,020
Pacific	17[3]	3	Tuna Purse - 25,608	998,712
		4	Tuna Albacore - 6,900	358,800
		3	Salmon Purse - 3,210	125,190
		3	Salmon Comb Troll - 8,190	319,410
		4	Salmon Gill Net (Alas) - 3,245	168,740
Gulf	4	2	Manhaden - 6,225	161,850
		2	Shrimp - 7,826	203,475
Other	1	NA	NA	NA
TOTAL	26			$2,958,097

(1) Six deaths from weather as contributing factor included.

(2) The median age at time of death is 39, the average retirement from active fishing is 52, the productive years lost are estimated at 13, loss is calculated by multiplying average year income x 13 x number of deaths. No attempt has been made to indicate potential increase in income over 13 year period.

(3) Deaths per geographic area has statistical support; however, distirbution of the deaths among the fisheries of the area is somewhat arbitrary. Maximums and minimums could be calculated by placing all the deaths for the particular area in the highest and lowest paying fishery.

Table 5.8 Estimated Loss of Income to Fishing Industry
Due to Injuries Caused by Adverse Weather

Area	Distribution of Deaths/Yr by Geographic Area (Average)	Number of Injuries Based on Fatalities (1)	Total Number of Days Lost (2)	Injury Distribution by Fishery (Total Days Lost)	Average Crew Member Income per Day ($)	Estimated Loss of Income ($)
Atlantic	4	512	1,536	768	Boston - 55	42,240
				768	Bedford - 49	37,632
Pacific	17 (3)	2,176	6,528	1,152	Tuna Purse - 97	111,744
				1,536	Tuna Albacore - 30	46,080
				1,152	Salmon Purse - 27	31,104
				1,152	Salmon Comb. Troll - 48 (4)	55,296
				1,536	Salmon Gill Net - 59	90,624
Gulf	4	512	1,536	768	Menhaden - 45	34,560
				768	Shrimp - 43	33,024
Other	1	(128)	(128)	(NA)	(NA)	(NA)
TOTAL	26	3,328		9,984		$482,304

(1) Based on 26 deaths and ratio of 128 injuries per fatality.

(2) Based on reportable injury (72 hours of incapacity). This estimate may be conservative. See Page 83 in Addendum where disability for fishermen averaged 47 days.

(3) Death per geographic area has statistical support; however, distribution of the deaths (therefore injuries) among the fisheries of the area is somewhat arbitrary.

(4) Average of salmon troller ($65) and tuna troller ($30).

written by domestic stock and mutual insurance companies for U.S. commercial fishing vessels are worth approximately $32 million, where, of this total, $22.4 million is for hull coverage and $7.6 million is for personnel and indemnity coverage. Of the American companies currently writing personal and indemnity insurance for the commercial fishing fleet almost all have suffered heavy underwriting losses. In general, it appears that those which still write P&I insurance, do so as an accommodation for clients who also place their hull insurance with the underwriter. Of the American companies writing hull insurance, the majority have obtained modest profits in the last five years, though to achieve this, the companies have not corrected the causal factors, but merely increased hull premiums by 55 to 118 percent. In analyzing the causal relationship relative to insurance rates, a U.S. Coast Guard study group estimated the effects of alternative safety programs on the frequency of accidents and subsequent insurance costs. The study concluded that if the safety programs were successful they would justify substantial cuts in premiums paid for hull insurance. However, the probabilities of significant savings in P&I insurance costs were not high. It was concluded that depending on the geographical area, premium reductions could range from 15 to 56 percent.

Turning to how SEASAT could affect premium rates, it was concluded that the satellite could potentially have an impact on 11 of 22 or 50 percent of the basic criteria used to

set rates. Of this, SEASAT could impact six directly and five indirectly (see Table 5.9). The safety programs outlined by the USCG respond to the problem of human error which, on the average, is the primary cause for 45 percent of all fishing vessel casualties. In a proportional relationship, it is assumed that SEASAT can respond to the adverse weather problem which, on the average, is the primary cause for approximately 15 percent of all fishing vessel casualties. On this basis, suggested reductions in hull insurance premium rates would range from 5 to 8 percent with a conservative average of 7 percent and a high average of 13 percent. Under these assumptions, SEASAT could provide the commericial fishing industry potential savings of \$1.6 to \$2.9 million annually due to hull insurance premium reductions. An additional savings could be realized for several mutual fishing vessel organizations which pool their monies for self insurance. These organizations are almost exclusively on the west coast, and benefit directly by reductions in claims through returns of surplus funds and investment income which is allocated to the members. As a result, rates tend to be significantly less than those the domestic or foreign insurance industry can provide. Insurance premiums written by the mutual fishing vessel organizations approximate \$1,849,000 per year. Some of these funds are used to hedge against catastrophis loss via reinsurance. The reinsurance costs approximate 20 percent of the total premiums, leaving

Table 5.9 The Insurance Rate Setting Structure and Areas Which SEASAT Could Potentially Impact

Rate Standards \ Criteria	Size Of Vessel	Type (Classification)	Adaptability To Trade	Motive Power	Materials & Structure (Construction)	Age	Profitable Operation	Regular Maintenance	Intelligent Supervision	Established or Initial Account	Claim History	Nationality	Natural Forces (Fog, Ice, Wind)	Topography	Season	Five-Year Premium & Loss Record	Reserve Requirements	Rate Leveling	Foreign Involvement	Deductibles	Lower Liability	Personal Evaluation All Factors
Type of Vessel					●	●																
Personal Factors							X		X		X											
Nature of Trade													X	X	X							
Statistical Experience																X						
Competition																		X	X			
Policy Conditions																				X	X	
Underwriter Judgement																						
Note Number (Attached Sheet)							1		2		3		4	5	6	7		8	9	10	11	

X SEASAT impact

● Major influence in rate derivation.

Table 5.9 The Insurance Rate Setting Structure and Areas Which SEASAT Could Potentially Impact (Continued)

1)	Direct	-	Increased productivity, better "fishability" and lower per unit costs
2)	Indirect	-	Indications of making good use of weather data
3)	Direct	-	Reduced weather damage claims
4)	Direct	-	Minimization of unexpected weather hazards
5)	Indirect	-	Ample warning to seek refuge
6)	Indirect	-	Special coverage of high weather risk areas
7)	Direct	-	Insurance companies would have to begin to segregate causal factors, but regardless, claims should be reduced
8)	Direct	-	Assessment of risks in areas are inconsistent, better records and reductions in claims should level out wide rate variability
9)	Indirect	-	As damage claims become reduced, domestic rates could stay competitive
10)	Direct	-	Insurers could offer more deductible options and owner/operators could reduce coverage in those areas most responsive to weather
11)	Indirect	-	Although injuries reductions can result by better weather prediction, large settlements are maintaining liability requirements at a high level

net premiums of approximately $1,479,000 per year. Assuming similar potential premium reductions for this market, based on casualty reductions, approximately $133,000 per year would be available as savings to the members. Reduction in commercial fishing hull premiums through the reduction of adverse weather casualties could result in potential savings of approximately $2.2 million per year in the domestic stock and mutual market and $133,000 per year in the mutual fishing vessel insurance organizations. Maritime laws and the Jones Act leave determination of liability to the litigation process. Recent court interpretations and generous jury verdicts have combined to increase the P&I risks substantially. Additionally, the underwriters have failed to assess the risk with any degree of accuracy as witnessed by consistent losses in the P&I sector. Based on this, it is unlikely that SEASAT benefits would result in P&I premium reductions in the near term. The potential savings estimated at $2.3 million per year must be viewed in light of the following:

1. This is not a straight through benefit to the party of concern (except for the mutual fishing vessel insurance organizations), the U.S. commercial fishing fleet, but is moderated through the insurance company
2. The assumption is that given a reduction in vessel casualties the underwriter will be amenable to reductions in premium rates. The fact, however,

is that in the majority of instances an underwriter does not even examine an account unless the loss ratio changes significantly. The standard criterion is a 40 percent loss ratio; if the ratio is greater, money is being lost and experienc should be looked at. This assessment is difficult In that ocean marine insurance companies do not segregate risks by causal relationships. The companies response is simply to adjust an account's rates to make it profitable over a three-to-five year period.

3. In support of this failure to segregate causes or maintain supportive statistics, it should be recalled that the controvery around the value of containers over breakbulk is several years old and no meaningful comparative loss ratios have been developed by underwriters
4. In a situation such as this, benefits attributable to SEASAT may be observable to the companies in terms of reduced casualties (and these companies would only consider this a trend after five years). However, unless companies begin to maintain casualty statistics they may consider the effect random.
5. Losses occur in unpredictable peaks rather than

> it regular average levels reflecting the underwriter's utility function. Although underwriters reinsure themselves to spread the large losses, they strive to build reserves for future peaks. This process either exerts an upward pressure on rates or blunts any argument for reductions.

On the other hand, if causal relationships could be established, significant benefits could accrue even if the benefits just took the form of smoothing-of-the-hull insurance

6. THE CANADIAN FISHING INDUSTRY

6.1 Introduction

A further case study of the utility of SEASAT information to the fishing industry of Canada was performed by the Canada Centre for Remote Sensing. The following sections report the results of the Canadian case study.

6.2 Dimensions of Canadian Fisheries Industries

The following summary table shows the quantities and values of sea fish landings for 1972, 1973 and 1974 (provisional estimates), without adjustments to constant dollars [6-11], for the Canadian fisheries industries.

Roughly speaking, groundfish are bottom feeding and caught on the bottom, while pelagic species feed at various depths and are caught at various depths. The distinction is important for the type of fishing gear, technique and management involved.

The Atlantic totals in the table following includes Newfoundland, Nova Scotia, New Brunswick, P.E.I. and Quebec provinces. The Pacific totals are for British Columbia. The variations of quantity and value of landings over the three-year period were substantial.

Table 6.1 Quantity and Value of Canadian Sea Fish Landings

Sea Fish Landings* Area/Fish Type	1972 Qty 10^6 lbs	1972 Value 10^6 \$	1973 Qty 10^6 lbs	1973 Value 10^6 \$	1974 Qty 10^6 lbs	1974 Value 10^6 \$
Atlantic Totals	1,871	142.0	1,802	168.5	1,532	162.0
Ground fish	1,046	61.2	1,104	81.0	834	73.2
Pelagic, estuarial	742	19.8	605	23.8	608	25.1
Mollusks, crustaceans	75	60.4	87	63.1	84	62.9
Other	8	0.6	6	0.6	6	0.8
Pacific Totals	338	75.1	389	130.4	279	91.3
Ground fish	54	16.8	45	14.3	37	9.4
Pelagic, estuarial	269	56.1	328	113.3	227	79.0
Mollusks, crustaceans	15	2.2	16	2.8	15	2.9
Other	-	-	-	-	-	-
Canada Totals	2,209	217.1	2,191	298.9	1,811	253.3
Ground fish	1,100	78.0	1,149	95.3	871	82.6
Pelagic, estuarial	1,011	75.9	933	137.1	835	104.1
Mollusks, crustaceans	90	62.6	103	65.9	99	65.8
Other	8	0.6	6	0.6	6	0.8

* These Figures exclude seaweeds and seals, worms, whales, etc., which may have local importance. See ref. 6-1.

On the Atlantic coast, including the Gulf of St. Lawrence, mollusks and crustaceans account for about 40 percent of the value of landings; lobsters alone account for almost 25 percent of the value of landings. Cod, flounders and soles, redfish, and haddock are the most important groundfish, in that order. Herring is by far the most important of the pelagic species.

On the Pacific coast, mollusks and crustaceans are much less important. Halibut is the most important groundfish. However, pelagic species account for over 80 percent of the value of landings; salmon alone accounts for about 75 percent.

The 1972 landed values of Canada's ten most valuable species were as follows, in order (2-2):

Lobster - Atlantic	$36.4 million
Cod - Atlantic	25.8
Scallops - Atlantic	19.3
Halibut - Pacific	13.5
Chum Salmon - Pacific	13.4
Herring - Atlantic	12.1
Coho Salmon - Pacific	10.6
Spring Salmon - Pacific	9.7
Redfish - Atlantic	9.4
Sockeye Salmon - Pacific	8.9

The order of importance has changed, historically, and will continue to change from time to time.

Inland fisheries are important in Canada, though their

value is far outweighed by coastal fisheries. Processing of landed fish is also an important industry, which depends directly on fish landings. The following table shows quantities and values of landings for both inland and coastal fisheries, and values of all fisheries products in 1972, classified by province [6.1]. Most of the value shown for Quebec is in sea fisheries.

The summary table, also following, shows the numbers and values (million dollars) of fishing craft in Canada in 1972, [6.1].

Table 6.2 1972 Values for Canadian Sea and Inland Fisheries

Province/Territory	Landings Quantity 10^6lb	Landings Value 10^6\$	Products Value 10^6\$
Newfoundland	651	35.7	100.6
Nova Scotia	633	66.4	142.1
New Brunswick	358	19.9	86.4
P.E.I.	57	9.5	20.1
Quebec	183	11.1	25.9
Subtotals	1882	142.6	375.1
Ontario	43	8.1	16.2
Manitoba	24	4.5	
Saskatchewan	11	1.6	
Alberta	5	0.7	15.5
Northwest Territories	4	0.3	
Yukon	-	-	
Subtotals	87	15.2	31.7
British Columbia	338	75.1	159.1
Totals	2307	233.9	565.9

Table 6.3 1972 Values, 10^6\$, of Canadian Fishing Craft Classified by Size						
Class of Craft	Atlantic Coast		Inland		Pacific Coast	
	Number	Value	Number	Value	Number	Value
Boats less than 10 tons	25,409	19.9	-	-	4,252	21.6
Vessels 10-24.9 tons	2,478	12.6	-	-	1,849	24.5
Vessels 25-149.9 tons	744	28.8	-	-	549	29.4
Vessels 150 tons, over	271	103.7	-	-	20	4.3
Total craft	28,902	165.0	1,686	5.4	6,670	79.8

The employment in primary fisheries operations in 1972 was as follows, [ref. 6.1].

Table 6.4 Employment in Canadian Sea and Inland Fisheries Classified by Province		
Province/Territory	Sea Fisheries	Inland Fisheries
Newfoundland	14,452	-
Nova Scotia	11,735	-
New Brunswick	5,067	94
P.E.I.	3,210	-
Quebec	5,277	566
Ontario	-	2,097
Manitoba	-	-
Saskatchewan	-	1,800
Alberta	-	1,547
Northwest Territories	-	-
Yukon	-	-
British Columbia	9,902	87
Totals	49,643	6,191

In summary, the total value of fisheries landings in 1972 was about \$234 million, and the value of products was about \$566 million. Total fish products exports were \$347 million. Employment was nearly 50,000 people in primary sea

fisheries operations, and over 6,000 in inland fisheries. Fisheries craft had a total book value of $250 million.

6.3 Future Potentials for Canadian Fisheries

Historically, major fishing fleets of several nations have operated in Canadian coastal waters. These fleets have harvested large catches and have long been considered a major cause of Canada's failure to increase its proportion of the total catch.

In recent years, Canada has taken several steps to strengthen the domestic fishing economy. The 12-mile exclusive fishing zone was established in 1964, and straight baselines for the 12-mile limits were drawn from headland to headland in 1967. Fishery closure lines were drawn in 1971 across the Strait of Belle Isle, Cabot Strait and the Bay of Fundy, bringing the Gulf of St. Lawrence and Bay of Fundy waters, for example, under exclusive Canadian jurisdiction for purposes of Atlantic fisheries, pollution control and marine resource management. Though these fisheries closing lines have been contested, Canada was able to conclude in 1971-72 phasing-out agreements with France, the U.K., Norway, Denmark, Spain and Portugal and, with the exception of the United States, these lines are now universally recognized. The USA opposition will, of course, disappear when the concept of 200-mile economic zones is adopted by the Law of the Sea Conference. There is also a Canada --USA Reciprocal Fishing Agreement, but this is limited to the traditional activities of both countries in each other's outer 9-mile zone.

It is important to distinguish between inshore and offshore coastal fisheries. For purposes of discussion, inshore fishing is considered to be within the 12-mile limits and the fisheries closing lines. On the Atlantic coast, offshore fishing is considered to be outside the 12-mile limits of the east coast of Labrador, the east and south coasts of Newfoundland, and the east and south coasts of Nova Scotia. Such offshore fishing falls within the ICNAF area (International Commission for the Northwest Atlantic Fisheries). For the purposes of statistical reporting and regulation, ICNAF has divided the northwest Atlantic into five main subareas:

1 - West Greenland

2 - Labrador

3 - The eastern and southern Newfoundland area, from the Strait of Belle Isle to Cabot Strait and including the continental shelf in this area and the Newfoundland banks

4 - The Nova Scotian area and the Gulf of St. Lawrence

5 - Georges Bank and the New England area of the Gulf of Maine.

Each of these subareas is in turn subdivided for convenience in research and regulations of fish populations, [6-3].

On the Pacific Coast, offshore fishing is considered to be outside the 12-mile limits of the mainland coast above Vancouver Island and outside the 12-mile limits of the west coast of Vancouver and Queen Charlotte Islands.

The offshore fisheries are important for two reasons. First, offshore areas are good places to go fishing. Second, offshore areas are the habitat of stocks of fish that are caught inshore. As the international offshore landings increase, stocks of some species are depleted and the inshore fisheries suffer the consequences.

Canada's coastal fisheries can grow substantially in the future only if:

1. The offshore landings are controlled to prevent undue depletion of the stocks that replenish the inshore fisheries
2. Canada obtains an increasing proportion of the offshore landings.

These requirements can be met only if Canada establishes its right to control fisheries at least out to the 200-mile limit.

For the purposes of a growth scenario, the following assumptions are made:

1. Canada will achieve functional control of its own coastal fisheries at least to the 200-mile limit, before 1985 when SEASAT and other operational remote sensing systems are feasible
2. Canada will further develop the technological capability to expand its offshore fisheries (e.g., operating under winter ice conditions in areas such as the Hamilton Bank, Labrador, using 55 meter and 64 meter freezer trawlers, ice-strengthened to Lloyd's Class 2, with 2500 BHP diesel

engines and fish-hold capacities of 485 and 685 cubic meters and provisions for 40 day voyages, [6-4].

3. The coastal fishermen will be able to adapt to the gradual change from inshore to offshore fishing. (The inshore fisheries have been the most important up to now in terms of employment and economic activity.) The trend to offshore fishing will require technological changes and investments in new vessels and plant, government support services (e.g., surveillance, research) and changes of lifestyle (e.g., 40 days at sea instead of 10 or 12 days at most for offshore Newfoundland).

4. The economics of production, demand and international competition will be favorable. Domestic and export demand will grow, with the U.S. continuing as Canada's largest export market for fishery products. New export markets will be sought and found. (It has been reported, for example, that the U.S.S.R. finds it uneconomical to fish in the ICNAF area, and, instead, may be prepared to import from Canada in the future.) The uncertainties are manifold, but the world food situation will cause increasing pressure for optimal management of fishery yields.

5. Total sustainable yields are limited, and Canada can increase its share of the catch two or threefold only if the foreign share is reduced commensurately.

Based on the above assumptions, and past performance of the Canadian industry, it seems reasonable to postulate at least a doubling and perhaps a tripling of the production quantities and value (1974 $) of Canadian fisheries by the year 2000, implying average growth rates of 3 to 4.5 percent per annum. Most of this growth would have to come from increased Canadian landings from the offshore fisheries.

6.4 Pacific Coast Fisheries Benefits of Remote Sensing

The following summary table shows the quantities and values of sea fish landings in British Columbia in 1972 and 1973, without adjustments to constant dollar terms. As can be seen, the increase in value of salmon from 1972 to 1973 was caused by remarkable price increases.

In Table 6.6, District 1 includes Horseshoe Bay and the Fraser River estuary and part of the Strait of Georgia, all in the vicinity of Vancouver. District 2 includes all of the coast from Margaret Bay (just above Vancouver Island) up to the international boundary of Alaska, and embraces the Queen Charlotte Islands. District 3 includes all of the mainland coast above Horshoe Bay to Margaret Bay, and all of the coast of Vancouver Island, thus including Queen Charlotte, Georgia and Juan de Fuca Straits. Most of the great salmon landings are in Districts 2 and 3, but a substantial landing occurs in District 1.

The fish landings generate production in onshore plants. The total value of sea fish products was $159 million in 1972

Table 6.5 Value and Landings in British Columbia Classified by Fish Type

Fish Type	1972 Quantity 10^6lbs	1972 Value 10^6 $	1973 Quantity 10^6lbs	1973 Value 10^6 $
Groundfish totals	54	16.8	42	14.1
Halibut	22	13.7	15	10.7
All other groundfish	32	3.1	27	3.4
Pelagic, estuarial totals	268	56.1	330	113.5
Herring	86	2.7	123	10.9
Salmon	164	50.3	185	100.0
All other pelagic, estuarial	18	3.1	22	2.6
Mollusks and crus acean totals	15	2.2	16	2.9
Crabs	2	0.7	3	1.2
All other mollusks, estuarial	13	1.5	13	1.7
Sea Fish totals	338	75.1	389	130.4

The following table shows a breakdown of landings of three important species by district in 1973.

Table 6.6 Value and Landings by District and Important Species in British Columbia

Fish Type	DISTRICT 1 Qty. 10^6lb	DISTRICT 1 Value 10^6 $	DISTRICT 2 Qty. 10^6lb	DISTRICT 2 Value 10^6 $	DISTRICT 3 Qty. 10^6lb	DISTRICT 3 Value 10^6 $	TOTAL Qty. 10^6lb	TOTAL Value 10^6 $
Halibut	-	-	14	10.0	1	0.7	15	10.7
Herring	-	-	45	4.1	78	6.8	123	10.9
Salmon	12	6.8	77	37.5	96	55.7	185	100.1

and $284 million in 1973. Based on these figures and the growth scenario of the preceding section, the following values of sea fish landings and products are postulated for Canada's Pacific coast fisheries, assuming a nominal 2:1 ratio of product value to landings value.

Year	Landings 10^6 \$	Products 10^6 \$
1980	150-175	300-350
1990	200-300	400-600
2000	275-400	550-800

The relevance of remote sensing systems in general, and SEASAT operational systems in particular, has not yet been firmly established in the case of Pacific offshore fisheries. However, the following possibilities exist:

1. Indirect application to fish location - e.g., through observation of coastal processes, upwelling, currents, turbidity, surface temperature, pollution and other factors that affect fish population feeding and migration. All SEASAT sensors would be applicable.
2. Indirect application to assignment of fishing vessels to known productive areas - e.g., by observing fishing fleet movements to determine which areas have already been visited and fished extensively. SEASAT Synthetic Aperture Radar (SAR) would be useful.
3. Direct application to the scheduling of fishing voyages to avoid adverse sea state and weather conditions.

4. Surveillance to prevent interference with fish nets and traps, and depletion of areas under conservation management.

In the absence of conclusive evidence, a parametric analysis can be made on a "what if" basis. What if remote sensing can lead to a one percent improvement in the utilization of fishing vessels, equipment and manpower? First, let us assume that almost all of the future growth to the year 2000 occurs in offshore halibut, herring and salmon fisheries of District 2 and 3. (Let us assume that remote sensing has potential application to 50 percent of Pacific fisheries in 1990 growing to 75 percent by 2000 A.D.) The following table shows the hypothetical potential benefits of remote sensing corresponding to improvements of 1, 2 and 4 percent in the utilization of resources required for the landing of sea fish only. Values are in millions of dollars (1974 $).

	Total	Applicable	Percent Improvement		
Year	Landings	Landings	1%	2%	3%
1980	$120-150	$ 60-75	$0.6-0.7	$1.2-1.5	$2.4-3.0
1990	170-220	110-140	1.1-1.4	2.2-2.8	4.4-5.6
2000	250-300	190-230	1.9-2.3	3.8-4.6	7.6-9.2

Assuming potential improvements on only 2 percent, which seems technically feasible and plausible, the benefits of remote sensing would be of the order of one and a half million dollars per year in 1980, increasing to 4 million per year by 2000 A.D.

6.5 Atlantic Coast Fisheries Benefits of Remote Sensing

The case for remote sensing benefits related to Atlantic coast fisheries seems much stronger than for the Pacific coast.

The nutrient-rich waters of the continental shelf in the Gulf of St. Lawrence and Atlantic sea fisheries contain a varied and valuable selection of marine life. Historically, fish species have supported a profitable fishing industry, but overfishing and pollution have recently led to a demise of fisheries and now threaten the future of fishing operations. Assuming that Canada will achieve functional control over pollution and resource management out to at least the 200-mile limit, the continental shelf will provide major opportunities for the expansion of Canadian fisheries. To maximize this potential, Canada will have to exercise a right of fisheries control not only to the 200-mile limit along the Northern and Southern Labrador Shelf, the Northeast Newfoundland Shelf and the Scotian Shelf, but well beyond the 200-mile limit along the tail of the Grand Bank (some 300 miles southeast of Cape Race, Newfoundland) and the outer slope of the Flemish Cap (some 450 miles east of Cape Race).

In the past two or three decades there has occurred a significant change in the pattern of fishing and employment. The Gulf and Atlantic fisheries, once heavily dependent on salt cod, have diversified into multi-species fresh and frozen fish. About 40 species of shellfish and finfish are now consumed domestically. There has occurred a gradual increase of interest

in offshore species such as redfish, and in the development of offshore fishing technology.

Cod is economically the most important of the groundfish species of the Atlantic fisheries, with Canadian landings of 325 million tons valued at $29.6 million in 1973 , [ref. 2-1]. The Hamilton Bank area, on the Southern Labrador Shelf, is the most productive of the offshore cod areas, equalling all the other areas combined and having a sustainable yield of 1,100 or 1,200 million pounds annually. Of the total of over 700 million pounds of cod landed from Hamilton Bank in 1973, for example, only 12.5 percent was accounted for by Canada while 87.5 percent was accounted for by the other ICNAF states (W. Germany 10.0 percent, E. Germany 6.7 percent, Poland 7.8 percent, Portugal 21.5 percent, Spain 12.1 percent, U.S.S.R. 23.1 percent and others 6.3 percent). The offshore fishing in the Hamilton Bank area has severely damaged the inshore fishery of the north-east coast of Newfoundland. Canada would greatly expand its landings of cod in the Hamilton Banks area if:

1. It were to develop fishing vessels that could fish under the heavy ice conditions encountered and
2. It could control the quotas of the other ICNAF nations within the 200-mile limit, [2-4].

Redfish, for example, is an important Atlantic groundfish species, with Canadian landings of 356 million pounds valued at $9.5 million in 1973, [6.1]. Redfish are common on the

continental slope along the margin of the shelf area. They are found off the south coast of Newfoundland, in the area of Flemish Cap, and around the edge of the Grand Bank up to Hamilton Bank in Labrador, [6-3], [6-5]. Of the total of nearly 80 million pounds of redfish landed in the Hamilton Bank area in 1973, for example, only 1 percent was accounted for by Canada, while over 62 percent was accounted for by the U.S.S.R., [6-4].

The relevance of remote sensing systems, particularly SEASAT, has not yet been firmly established in the case of the Atlantic inshore and offshore fisheries. However, the following applications appear promising.

1. <u>Monitoring of dynamic changes of currents</u>

   There are four main currents which mix and interact in a complex way, affecting the fisheries. In the spring and summer, the West Greenland Current arcs westward and southward to join the cold Labrador Current that flows southward from Davis Strait down the coasts of Labrador and Newfoundland, passing over the Great Bank. The warm Gulf Stream flows up along the U.S. coast and then eastward, just south of the Grand Bank, mixing with the Labrador Current. This mixing produces waters of intermediate temperature that cover parts of the southwestern slope of the Grand Bank (south of Newfoundland) in winter, and flood over the bank in summer. The resulting slightly higher temperatures make the southwestern Grand Bank more suitable for Haddock than Cod, for example, [6-3].

   In the spring and summer, the Gaspe Current flows from the St. Lawrence River through the Gulf of St. Lawrence, past Prince Edward Island, and circles Nova Scotia all

the way to the Bay of Fundy. It interacts in the Gulf with part of the Labrador Current, which circles the south and west coasts of Newfoundland. It also interacts with another part of the Labrador Current, which splits southwest along the slope of the Scotian Shelf (east and south of Nova Scotia). Parts of both the Gaspe Current and the Labrador Current interact with the Gulf Stream south of Nova Scotia. Another part of the Labrador Current interacts with the Gulf Stream and splits eastward from the Grand Bank.

The pattern of circulation and interaction of the various parts of the Labrador and Gaspe Currents and the Gulf Stream is exceedingly complex and variable. Currents are strong and variable in the Slope Water along the margin of the Scotian Shelf and southwest Grand Bank, for example. The currents provide the conditions for productive fisheries, and also the conditions for difficult operations.

2. <u>Monitoring of sea surface temperatures</u>

   The sea temperatures are variable with the currents described above, and the currents are highly variable.

3. <u>Monitoring of upwelling, turbidity, pollution in the Gulf and on the continental shelf.</u>

4. <u>Monitoring of sea ice</u>

   Fishing operations, as well as transportation, in the Gulf and on the continental shelf, are affected by sea ice.

5. <u>Monitoring of sea state</u>

6. <u>Surveillance of fishing vessels</u>.

   SEASAT operational systems, in conjunction with other satellite systems (LANDSAT, NOAA), and airborne remote sensing systems (e.g., DND, DOE's Ice Central), and surface vessels (e.g., Coast Guard, DOE Oceanography), would provide a powerful means of dealing with the six monitoring applications outlined above.

In addition to obvious benefits related to sovereignty and science, there would be significant economic benefits in the following categories:

a. Indirect application to fish location e.g., through observation of currents, upwelling, turbidity, temperature and other factors that affect fish migrations and feeding

b. Indirect application to assignment of fishing vessels to known productive areas--e.g., by observing fishing fleet movements to determine which areas have already been visited and fished extensively. SEASAT SAR would be useful.

c. Direct application to the scheduling and routing of fishing voyages to avoid adverse sea state and sea ice conditions. SEASAT SAR would be particularly useful.

d. Surveillance to prevent interference with nets and traps and depletion of areas under conservation management. (e.g., trawlers of the U.S.S.R. have been accused of damaging lobster traps while dragging fish nets along the bottom, sometimes to the extent of $100,000 to $200,000 in a season.

As a basis for a parametric analysis such as in the preceding section, let us assume that almost all the future growth of the sea fisheries to the year 2000 will occur in the offshore areas of the Labrador Shelf, Northeastern Newfoundland Shelf, Grand Bank and Scotian Shelf. The value of Atlantic sea fish landings was about $142 million in 1972 and the value of sea fish products was about $348 million. Excluding mollusks and crustaceans, the value of landings was $82 million in 1972 and the value of products was about $252 million.

Assuming a nominal 2.5/1 ratio of products to landings of sea fish on the Atlantic coast, and a two to threefold Canadian growth by 2000 A.D., one obtains the following forecast. (See scenario in Section 2.2, in which the Canadian growth depends on increasing Canada's share of the catch at the expense of the foreign share.)

Year	Landings 10^6 $	Products 10^6 $
1980	190-210	480-530
1990	250-350	630-880
2000	320-480	800-1200

Assuming potential improvements of 1, 2 and 4 percent in the utilization of resources required for the landing of sea fish only, one obtains the following table of corresponding potential benefits of remote sensing (millions of 1974 dollars).

Year	Total Landings	Applicable Landings	Percent Improvement 1%	2%	4%
1980	$190-210	$ 95-105	$0.9-1.0	1.9-2.1	3.8-4.2
1990	250-350	160-220	1.6-2.2	3.2-4.4	6.4-8.8
2000	320-480	240-360	2.4-3.6	4.8-7.2	9.6-14.4

Assuming potential improvements of only 2 percent, which seems technically feasible, and perhaps conservative, the benefits of remote sensing would be of the order of two million dollars ($2,000,000) per year in 1980, increasing to about six million dollars ($6,000,000) per year by 2000 A.D.

6.6 Summary of Fisheries Benefits of Remote Sensing

The following table shows potential benefits of remote sensing of Pacific and Atlantic fisheries, under the stated scenario and assumptions. The table also shows realistic benefits, under the assumption that learning and the development of operational systems take time. As to the validity of the Canadian study assumptions on improvements in operational efficiency, a recent study by the Gulf University Research Corporation, estimated a 4 percent improvement in offshore operational efficiency and an 11 percent inshore improvement. The Gulf University study was restricted to the Gulf of Mexico fishery. It is assumed that 10 percent of potential benefits could be achieved in 1980, 80 percent in 1990 and 100 percent in 2000 A.D.

CANADIAN SEASAT STUDY

SUMMARY OF POTENTIAL BENEFITS OF REMOTE SENSING APPLIED TO CANADIAN FISHERIES, ATLANTIC AND PACIFIC AREAS

Potential Million Dollars per Annum (1974 $)

	1978	1980	1990	2000
Pacific Fisheries	-	0.6-3.0	1.1-5.6	1.9-9.2
Atlantic Fisheries	-	0.9-4.2	1.6-8.8	2.4-14.4
Totals	-	1.5-7.2	2.7-14.4	4.3-23.6

Realistic Million Dollars per Annum (1974 $)
Assuming Learning and Development Factors

	1978	1980	1990	2000
Learning Factor %	-	10%	80%	100%
Pacific Fisheries	-	0.1-0.3	0.9-4.8	1.9-9.2
Atlantic Fisheries	-	0.1-0.4	1.3-7.0	2.4-14.4
Totals	-	0.2-0.7	2.2-11.8	4.3-23.6

Note: The ranges of potential benefits span the extremes of alternative assumptions:

- growth to 2000 A.D. doubling to tripling,
- applicable fisheries areas 50% in 1980 to 75% in 2000,
- percent improvement of operational efficiency 1% to 4%.

7. GENERALIZATION OF FISHERIES CASE STUDY

7.1 Introduction

World population expansion and overutilization of land resource have created a great interest in the ocean as an alternative source of support. The world fishery supply, one of the important products of the world's oceans, has two properties which as a factor of production make it especailly vulnerable to overexploitation:

(1) it is relatively fixed and

(2) it is of common property in nature.

Mainly because of these two distinguishing traits, the world fishery situation has been characterized in some cases by overfishing, decreases in physical output, and increases in the prices of certain species. If poor management of certain fishery resources is avoided, the world fishery resources can continue to be an essential and very necessary support for the population. However, if present management or lack of management of fishery resources is continued, world fisheries' products can cease to be the important source of human sustenance that they have been until now.

7.2 Demand for and Consumption of Fishery Products

Demand for world fishery resources is likely to increase, in other words, to follow past trends. World population is expected to continue expanding, and, according to Bell

[3-23, p.544] "... except for extraordinarily unusual price and income elasticities, the main determinant of a country's consumption of a fishery product revolves around the size of the population." Important also in predicting future demand and consumption trends, is the fact that world fishery consumption has embodied a tendency to increase at a greater rate than the increase in the rate of population expansion. In the period from 1958 to 1965, world fishery consumption increased 7.0 percent annually while human population increased 2.0 percent per year. The consumption of no other basic food commodity increased at this rate during this period.

Although demand for fishery products in general is expected to rise, there is an important question that has to be raised as to which species of fish will be the ones to command an increase in future demand. Demand for fishery products has in the past been constructed in a few so called preferred species. These preferred species have been exploited without concern for their overutilization. Fishery industries have been spending excessive amounts of capital and labor in order to keep up with the demand for these preferred species. It is expected that, if past trends continue, demand for some of these preferred types will outstrip the maximum supply potential before 1985. (See Table 7.1.)

If the past level of fish consumption, consumer preference and the level of technology continues, consumption for the preferred species will continue to rise although per capita

Table 7.1 World Demand for Species Fished

Species*	Year World will reach MSS**
Salmon[a]	1970
Halibut	1970
Groundfish[b]	1970
Crabs	1980-85
Fishmeal (i.e., species for reduction)	1980
Lobsters	1985
Tuna[c]	2000
Shrimp	2000
Sardines	2000+
Scallops[d]	2000+
Clams	2000+

* Aquaculture not assumed. MSS = Maximum Sustainable Supply

**For halibut and salmon projections cannot go below Maximum Sustainable Yield (MSY) because of existing regulations to protect the resource from overfishing. Oysters were excluded from the above list because of aquaculture augmenting natural stock supplies.

[a] does not include the possibility of expanded supply through hatchery operations and stream improvements

[b] Excludes lake and lake-like fish.

[c] Excludes Central Pacific Skipjack.

[d] Includes recent discovery of Calico Scallops.

Source: Bell, Frederick W., et al, "The Future of the World's Fishery Resources to the Year 2000", Proceedings of the Marine Technology Society, 1971, pp. 541-554.

consumption of fish in general will remain stable or decline. Price for those preferred species will increase, due mainly to cost pressures since excessive inputs of capital will be needed in order to produce those fully exploited species. Only the affluent segment of the population will be able to pay the higher prices of preferred species and per capita consumption will decline. If past and present trends continue, the process of overexploitation of some species will continue and preferred species will continue to be endangered. Neglected species will in turn continue to be underutilized and will often be sold at low prices in order to be reduced to fishmeal. It would be interesting to point out here that the world disposition of fish catch (if other factors remain the same and assuming no supply constriants) will be mostly for human consumption and not for other purposes such as reduction to fishmeal. (See Table 7.2.)

7.3 Supply of Fishery Products

Supply of fish products has increased in order to keep pace with demand, and should continue to rise if it is to fulfill demand. However, there are important supply constraints. Table 7.3 shows world nominal catch for the years 1965-1973 and fish catch of each continent as a percentage of the total world catch. Tables 7.4 and 7.5 show nominal catch for the world and principal fishing areas, and a forecast made for the years 1974-2000 assuming no supply constraints.

However, assuming no major changes, "aggregate fish consumption (including fishmeal) for the world will expand

Table 7.2 Disposition of Catch: World and U.S.A. (1965-2000)

	WORLD (000,000 metric tons)		U.S.A. (000 metric tons)	
	Human Consumption	Other Purposes	Human Consumption	Other Purposes
History				
1968	39.9	24.0	1785.9	694.4
1969	40.2	22.5	1696.0	795.1
1970	43.5	26.5	1819.4	957.1
1971	44.7	25.5	1755.9	1063.6
1972	45.1	20.4	1655.2	994.3
1973	47.2	18.5	1681.1	988.8
Forecast				
1974	48.9	19.3		1168.2
1975	50.7	18.4		1256.3
1976	52.5	17.6		1350.9
1977	54.3	16.8		1452.7
1978	56.2	16.0		1562.2
1979	58.2	15.3		1680.0
1980	60.2	14.9		1806.6
1981	62.4	13.9		1942.7
1982	64.6	13.3		2089.1
1983	66.8	12.7		2246.6
1984	69.2	12.1		2415.9
1985	71.6	11.6		2598.0
1986	74.2	11.0		2793.8
1987	76.8	10.5		2937.4
1988	79.5	10.0		3230.8
1989	82.3	9.6		3474.2
1990	85.2	9.1		3736.1
1991	88.2	8.7		4017.6
1992	91.3	8.3		4320.4
1993	94.5	8.0		4646.0
1994	97.8	7.6		4996.2
1995	101.3	7.2		5372.7
1996	104.9	6.9		5777.6
1997	108.6	6.6		6213.1
1998	112.4	6.3		6681.3
1999	116.4	6.0		7184.9
2000	120.5	5.7		7726.3

Data for years 1968-1973 have been obtained from:
Food and Agriculture Organization, Yearbook of Fishery Statistics, Catches and Landings, Vol. 36, Rome:FAO, 1973.

Years 1974-2000 have been forecasted through a time series analysis.
Forecasting equation for world nominal catch used for human consumption. n 24.48e$^{.035t}$.

Forecasting equation for world nominal catch used for purposes other than human consumption: n = 49.08e$^{-.047t}$.

Table 7.3 Fish Catch*: World, U.S.A. and Individual Continents

Year	World	U.S.A.	Africa	North and Central America	South America	Asia	Europe	Oceania	USSR
1965	53,200.0 (100%)	2,696.2 (5.1%)	3,160.0 (5.9%)	4,450.0 (8.4%)	9,190.0 (17.3%)	20,260.0 (38.1%)	10,890.0 (20.5%)	150.0 (.3%)	5,100.0 (9.6%)
1966	57,300.0 (100%)	2,515.3 (4.4%)	3,390.0 (5.9%)	4,430.0 (7.7%)	11,130.0 (19.4%)	21,250.0 (37.1%)	11,570.0 (20.2%)	170.0 (.3%)	5,350.0 (9.3%)
1967	60,400.0 (100%)	2,405.5 (4.0%)	3,770.0 (6.2%)	4,380.0 (7.3%)	12,200.0 (20.2%)	22,060.0 (36.5%)	12,060.0 (20.0%)	180.0 (.3%)	5,780.0 (9.6%)
1968	63,900.0 (100%)	2,451.7 (3.8%)	4,250.0 (6.6%)	4,640.0 (7.3%)	13,010.0 (20.4%)	23,820.0 (37.3%)	11,890.0 (18.6%)	190.0 (.3%)	6,080.0 (9.5%)
1969	62,700.0 (100%)	2,489.1 (4.0%)	4,300.0 (6.9%)	4,560.0 (7.3%)	11,350.0 (18.1%)	24,440.0 (38.9%)	11,340.0 (18.1%)	170.0 (.3%)	6,500.0 (10.4%)
1970	70,000.0 (100%)	2,776.5 (4.0%)	4,400.0 (6.3%)	4,930.0 (7.0%)	14,860.0 (21.2%)	26,300.0 (37.6%)	11,970.0 (17.1%)	200.0 (.3%)	7,250.0 (10.4%)
1971	70,200.0 (100%)	2,819.5 (4.0%)	4,130.0 (5.9%)	5,090.0 (7.3)	13,220.0 (18.8%)	28,100.0 (40.0%)	12,060.0 (17.2%)	230.0 (.3%)	7,340.0 (10.5%)
1972	65,500.0 (100%)	2,649.5 (4.0%)	4,600.0 (7.0%)	4,880.0 (7.5%)	6,790.0 (10.4%)	28,880.0 (44.1%)	12,330.0 (18.8%)	230.0 (.4%)	7,760.0 (11.8%)
1973	65,700.0 (100%)	2,669.9 (4.1%)	4,800.0 (7.3%)	4,940.0 (7.5%)	4,260.0 (6.5%)	30,240.0 (46.0%)	12,530.0 (19.1%)	260.0 (.4%)	8,620.0 (15.1%)

*Catch in thousand metric tons, 1965-1973.

Fish catch of each continent as a percentage of the world total is given in parentheses.

Source: Food and Agriculture Organization, Yearbook of Fishery Statistics, Catches and Landings, , 1973.

Table 7.4 World Nominal Catch (1965-2000)*

(nominal catch in thousand metric tons)

HISTORICAL

Year		Year	
1965	53,200.0	1970	70,000.0
1966	57,300.0	1971	70,200.0
1967	60,400.0	1972	65,500.0
1968	63,900.0	1973	65,700.0
1969	62,700.0		

FORECAST

Year		Year	
1974	72,189.5	1988	105,779.3
1975	74,186.7	1989	108,705.8
1976	76,239.1	1990	111,713.2
1977	78,348.3	1991	114,803.8
1978	80,515.9	1992	117,980.0
1979	82,743.4	1993	121,244.0
1980	85,032.6	1994	124,598.3
1981	87,385.1	1995	128,045.4
1982	89,802.7	1996	131,587.9
1983	92,287.1	1997	135,228.3
1984	94,840.3	1998	138,970.0
1985	97,462.2	1999	142,814.2
1986	100,160.6	2000	146,765.3
1987	102,931.6		

*Data for the years 1965 to 1973 have been obtained from: Food and Agriculture Organization. Yearbook of Fishery Statistics, Catches and Loadings, Vol.36 (Rome: FAO, 1973).
Years 1974-2000 have been forecasted through a time series analysis. Forecasting equation for world nominal catch: $z=n=41825.01983e^{.02729t}$.

Table 7.5 Nominal Catches by Major Marine Areas (in Thousand Metric Tons) (1965-2000)*

Year	Inland Waters	Marine Areas		
		Atlantic Ocean	Indian Ocean	Pacific Ocean
History				
1965	7,590	19,936	1,882	23,803
1966	7,910	20,886	2,056	26,443
1967	7,760	22,200	2,072	28,399
1968	8,000	23,070	2,187	30,618
1969	8,290	22,617	2,222	29,520
1970	9,020	23,837	2,409	34,680
1971	9,560	23,667	2,695	34,260
1972	9,610	24,546	2,442	28,847
1973	9,760	25,614	2,650	27,033
Forecast				
1974	10,235	26,858	2,804	32,667
1975	10,604	26,964	2,904	33,415
1976	10,987	28,373	3,049	34,180
1977	11,384	28,486	3,179	34,962
1978	11,795	29,279	3,315	35,762
1979	12,220	30,094	3,456	36,581
1980	12,662	30,391	3,603	37,418
1981	13,119	31,792	3,757	38,274
1982	13,592	32,677	3,917	39,150
1983	14,083	33,586	4,085	40,046
1984	14,591	34,521	4,258	40,963
1985	15,118	35,482	4,405	41,901
1986	15,663	36,469	4,629	42,860
1987	16,229	37,484	4,828	43,841
1988	16,814	38,527	5,033	44,844
1989	17,422	39,599	5,248	45,870
1990	18,050	40,703	5,472	46,920
1991	18,702	41,834	5,706	47,994
1992	19,377	42,998	5,949	49,093
1993	20,076	44,195	6,203	50,216
1994	20,801	45,425	6,468	51,366
1995	21,552	46,689	6,743	52,541
1996	22,330	47,988	7,031	53,744
1997	23,136	49,324	7,331	54,974
1998	23,971	50,697	7,644	56,232
1999	24,836	52,108	7,970	57,519
2000	25,733	53,558	8,310	58,836

*Data for the years 1965-1973 have been obtained from: Food and Agriculture Organization. Yearbook of Fishery Statistics, Catches and Landings, Volume 36 (Rome: FAO, 1973).

Years 1974-2000 have been forecasted through a time series analysis. Forecasting equation for:

A. Inland Waters: $Z=n=5,035.962758e^{.03546t}$

B. Atlantic Ocean: $Z=n=15,150.9725e^{.027}$

C. Indian Ocean: $Z=n=1216.02181^{.04178t}$

D. Pacific Ocean: $Z=n=20,775.39109^{.02263t}$

from approximately 125.8 billion pounds in the 1965-1967 base period to 184.1 billion pounds (round weight) by the year 2000, an increase of 46.3 percent." (See Bell [3-28], p. 549.) Unless appropriate policies were taken, supply would fall short of demand in the not so distant future. Critical problems of resource supply are occurring or about to occur for groundfish, salmon, halibut, lobsters, crab and fishmeal. (See Table 7.6.) The Bell study provided a projection for 1975 and 2000 of demand for the world's fisheries divided into thirteen major fish species (see Table 7.7), assuming no major change in situation. The level of exploitation in 1970 by geographic area rather than species is given in Figure 7.1. This chart is from Robinson and Crispoldi [3-2, p.26].

7.4 Future Developments in World Fisheries

The trends in demand and supply may not continue if certain developments take place. Demand for the presently "neglected" species may increase if consumers become aware of the great variety of fish species which can be substituted for some of the preferred ones and be just as nutritious and palatable. If consumers demand these less traditional species, the fishery industry can provide them. If demand for the less preferred species is increased, there is likely to be a decrease in the prices of the preferred species.

As far as the supply of fishery products is concerned, the prevailing judgment of authorities is that traditional

Table 7.6 Ranking of Fisheries on the Basis of Project Utilization

Species	Year Fully Utilized at MSS	Region Problems
Halibut	Presently	At MSY and inefficiently utilized[1]
Salmon	Presently	At MSY and inefficiently utilized[2]
Groundfish	1970	Overfishing in Northwest and Northeast Atlantic
Crab	1980	Overfishing in North Pacific, near MSY in West Central Atlantic
Lobster	1985	Nearly at MSY in Southwest Atlantic and Southwest Pacific
Shrimp	Before 2000	Eastern Tropical Yellow Fin nearly at MSY
Tuna	Before 2000	
Scallops	2	At MSY in Northeast Atlantic
Clams	3,4	
Sardines	5	
Oysters	4	
Fishmeal	1980	Northwest Atlantic at MSY

[1]Inefficient fishery management policies in effect.

[2]By 2000 only 28% of MSY is expected to be utilized when calico scallops are included.

[3]By 2000 only 87% of MSY is expected to be utilized without additional aquaculture.

[4]Infinitely elastic supply, within relevant range with additional aquaculture.

[5]Infinitely elastic supply, within relevant range as food fish.

MSY: No concensus - 120 million metric tons = middle ground of expert judgments as to level of total MSY.

Source: Bell, Frederick W., et. al., "The Future of the World's Fishery Resources to the Year 2000", Proceedings of the Marine Technology Society, 1971.

Table 7.7 Projections of Nominal Catch by Species, for the U.S.A. and World for 1975 and 2000

Year	World				U.S.A.			
	Quantity (Million Pounds)	Real Price ¢/lb.	% of MSY +	% of MSS ++	Quantity (Million Pounds)	Per Capita Consumption in Pounds	Real Price ¢/lb.	U.S.A. as Percentage of World
Species: Groundfish								
1975	15,300	11.3	76	99	1,250	5.69	12.7	8.2
2000	10,500	28.3	52	68**	830	2.69	31.8	7.9
Species: Tuna								
1975	3,210	18	82	88	1,215	5.54	14	38
2000	3,650	30	94	100	1,395	4.53	23	38
Species: Salmon (L.D.R.)								
1975	1,069	25.5	100	100	325	1.48	19.0	30.4
2000	1,069	37.7	100	100	346	.12	28.1	32.4
Species: Salmon (Elastic Supply)								
1975	1,126	24.2			338	1.54	18.0	30.0
2000	1,590	24.2			474	1.54	18.0	29.8
Species: Halibut[2]								
1975	129	32	100	100	88	.40	23	68
2000	129	52	100	100	89	.29	38	69
Species: Sardines (Elastic Supply)								
1975	3,228	31			148	.67	36	4.6
2000	5,225	31			208	.68	36	4.0
Species: Shrimp								
1975	2,350	46	72	72	840	3.83	41	36
2000	3,260	94	99	99	1,320	4.29	84	40
Species: Lobsters								
1975	383	81	90.3	90.3	258	1.18	87	67.4
2000	320	311	75.5	75.5	242	.79	336	75.6
Species: Crabs								
1975	1,060	15	84	85	520	2.37	9.8	49
2000	850	114	67	68	425	1.38	114.0	50
Species: Clams (L.D.R.)								
1975	1,180	3.6	67	67	560	2.55	3.6	47
2000	1,530	4.8	87	87	690	2.24	4.8	45

Table 7.7 Projections for 1975 and 2000 - (continued)
(Round Weight)

Year	World				U.S.A.			
	Quantity (Million Pounds)	Real Price ¢/lb.	% of MSY +	% of MSS ++	Quantity (Million Pounds)	Per Capita Consumption in Pounds	Real Price ¢/lb.	U.S.A. as Percentage of World
Species: Clams (Elastic Supply)								
1975	1,210	3.5			570	2.60	3.5	47
2000	1,970	3.5			840	2.73	3.5	43
Species: Scallops (With Calico Scallops)								
1975	520	7.3	20	20	335	1.53	6.8	65
2000	710	7.6	28	28	500	1.62	7.0	70
Species: Scallops (Without Calico Scallops)								
1975	490	7.8	54	58	320	1.46	7.3	65
2000	650	9.0	71	77	450	1.46	8.3	69
Species: Oysters (Elastic Supply)								
1975	2,686	5.3			639	2.91	5.5	23.8
2000	5,409	5.3			896	2.91	5.5	16.6
Species: Other Food Fish								
1975	72,000	10.4	47	47	1,380	6.29	10.4	1.9
2000	118,000	12.4	77	77	1,623	5.29	12.4	1.4
Species: Fish Meal								
1975	59,900	1.3	3,228	90	95	9,250	1.3	15.4
2000	33,500	7.8	5,225	55	58	5,700	7.8	17.0
All Seafood								
1975	163,003.71					7,568		
2000	184,154.64					8,714		

1. Maximum Sustainable Supply. This represents the maximum point of the world supply function which, in some instances, may be less than MSY because of different rates of regional exploitation.

2. Since 1933, the catch of most of the world's halibut has been regulated under a treaty between the U.S.A. and Canada.

3. Included here, to show utilization of the herring-like resource.

4. Including utilization of the resource for sardines.

* L.D.R. function used unless otherwise specified.

** It is important to note that the reason for the low rate of utilization is that the fishery is operating on the other side of MSS.

+ MSY = Maximum sustainable yield.
++ MSS = Maximum sustainable supply.

Source: Bell, Frederick W., etal, "The Future of the World's Fishery Resources to the Year 2000." Proceedings of One Marine Technology Society, 1971.

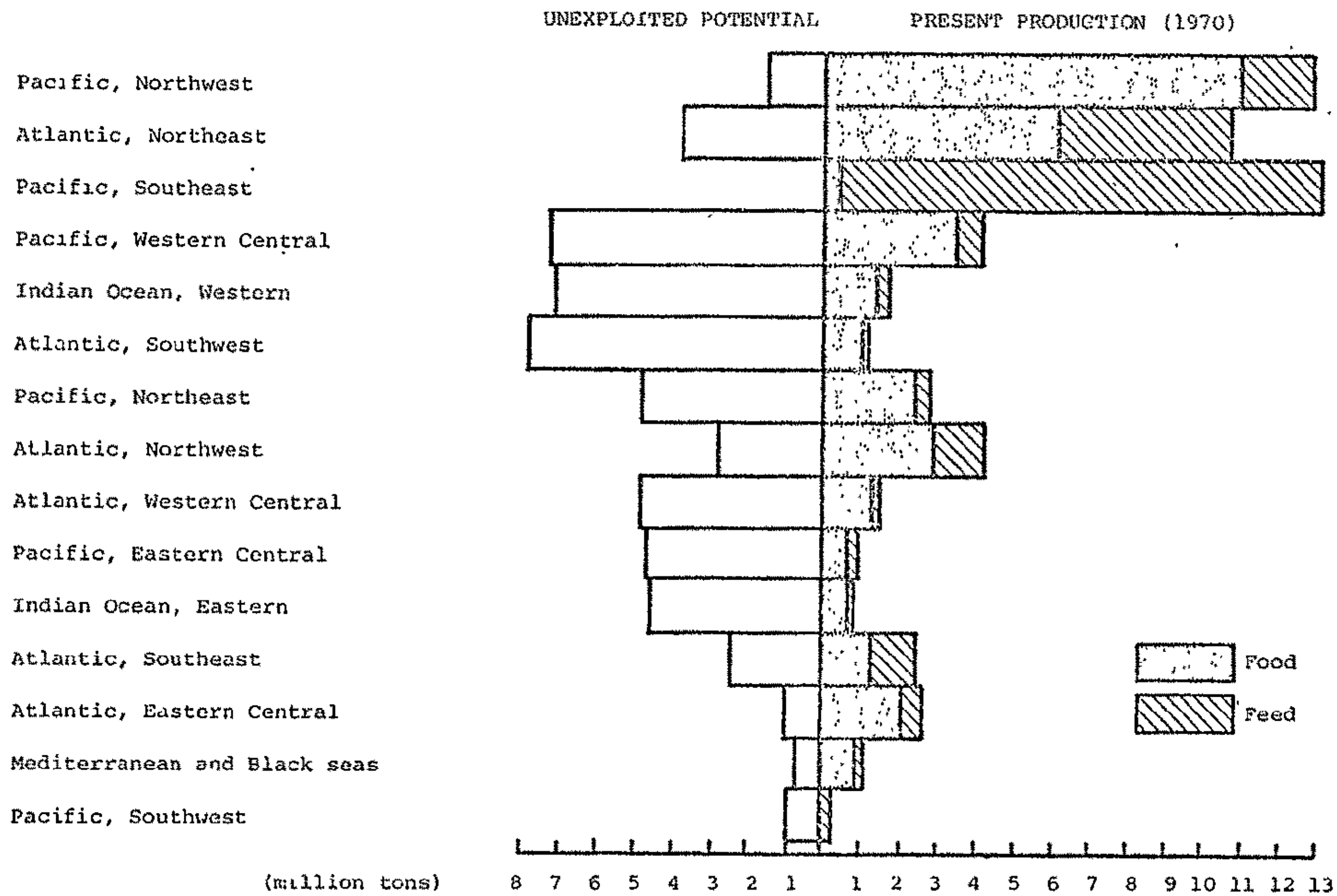


Figure 7.1 Production and Potential of the World's Oceans, 1970

supply sources of most species already preferred in the developed countries cannot, in most cases, be increased very much beyond recent levels. (See Committee on Commerce, [7-25, p. 53].) However, fish farming or aquaculture, and research and development in harvesting efficiency could be developed in many parts of the world for both preferred and traditional species. The Japanese have led the way in the aquaculture field and they already farm 100 percent of their trout, 88 percent of their eel, 72 percent of their carp, 14 percent of their Creecian carp and 10 percent of their ager.

Research and development of better fishing techniques would profit by better knowledge of aggregation techniques since "many marketable species are not harvested at present because the individual members of the stock are not sufficiently aggregated to allow harvesting at present prices." (See Bell [7-23, p. 553].) Short-term forecasting, new technology and changes in fisheries management may lead to significant changes. Also, studies about the internal dynamics of the oceans and about the various "neglected" species may greatly shape developments.

If the world fishery situation remains the way it has been in the past and is presently, the economic value of marketed catch will be concentrated in a few species which are being overexploited, and other species will continue to be underutilized. This underutilization of neglected species and overutilization of preferred ones will lead to a more severe resource depletion, decrease in productivity, increase

in prices of preferred species; decrease in profitable operations and stagnation, or even decline, of the per capita consumption of fish products. However, favorable changes could be in store for the world fisheries but it is difficult to foretell and quantify the effects that particular changes could have.

7.5 The Economics of Fisheries Management

The economic theory of fisheries management is well developed in principle and practice. The theoretical literature dates back to Volterra's article in 1931 [3-1]. The development of the theory may be seen in Lotka [3-19], Gordon [3-18], Scott [3-17], Turvey [3-21], Smith 1968 [3-8], Smith 1969 [3-9], Plourde [3-14], Clark [3-20] and Neher [3-15]. Some practical applications include the Food and Agricultural Organization [3-4], Cheung [3-13], Schaefer [3-2] and Beverton and Holt [3-16]. The technical discussion below will use the terminology as found in Neher.

The basic point of the theory is that given the population of a particular fishery, their reproductive rate, the operating cost and capability of the predator fleet, there is some optimal quantity of catch to strive for each year. Overextending this catch leads to losses in future years which will not be offset by the extra catch in the present. On the other hand, underexploitation of a fishery leads to the loss of an economically accessible fishery resource through natural depletion,

which cannot be captured in the future. The knowledge required to determine this optimal catch each year includes:

- The expected fishery population
- The natural reproductive rate of that fishery
- The market price of the fish on the quay
- The size of the fleet
- Costs associated with fleet operation.

As indicated earlier in this study, the operational SEASAT can play an important role in the estimation of the expected fishery population. Recent experience (for instance, as in the specific example above of the tropical tuna fishery) has shown that the state-of-the-art in fishery population forecasting is far from perfect.

Estimation of the reproductive rate can be found either in (1) published sources, (2) estimated from historical data on population and catch per year, or (3) made from some reasonable assumptions. The remaining economic variables of the market for fish and the economic operation of the fleet can be found directly. Why then, is there presently no attempt to achieve optimal catch each year in the major fisheries of the world? The reasons include:

- Miscalculation of fish population
- Miscalculation of the optimal catch
- Lack of international cooperation in establishing and achieving quotas (through lack of communication, ignorance or cheating on quotas)

- Lack of clearly defined responsibility in the management of a fishery (often due to disputes over territorial waters).

The last two reasons mentioned are presently being studied by the United Nations. A summary of this activity is given in Storer and Backstael's, "Law of the Sea and the Fisheries," [7-26]. Although the political resolution of these sensitive questions will take many years, the assumption will be made that in the years 1985-2000 sufficient progress will be made in the management of fisheries that estimates of optimal catches will lead to an actual catch which will approximate the optimal.

In order to estimate the benefits of SEASAT in the fishery management procedure, the following steps would have to be accomplished.

1. Collection of the economic data mentioned above.
2. Simulation of the fishery population estimation <u>without SEASAT</u> (with the appropriate distribution and standard error of estimate) for the period 1985-2000.
3. Estimation of the baseline present value of the fishery yield over the years 1985-2000, using the standard fishery management model (the Volterra quadratic fishery model).
4. Analysis of the improvement in fishery population estimation <u>with SEASAT</u> (the decrease in the standard error).

5. Simulation of the fishery population estimation with SEASAT for the period 1985-2000.
6. Recalculation of the present value of the fishery yield over the years 1985-2000, using the standard fishery management model.
7. The resulting benefit attributable to SEASAT would be the difference in value between the results of step 3 and step 6.

A technical discussion of the Volterra quadratic fishery model follows. As a natural resource to be optimized, fish present a number of characteristics which distinguish them from other natural resources. These include the common property nature of fish in the open sea, the reproductive or biological nature of this capital and the special diseconomies associated with fisheries. Diseconomies occur in regard to stock (as the population decreases cost per catch increases immediately), mesh (finer mesh netting means younger fish are captured and cost per catch will rise in future years) and crowding of vessels (as the size of the active fleet in a given fishery grows the cost per catch increases).

Assume the productive capacity is defined as:

$$x = Aab$$

where

x = prey captured (fish or catch)

a = predator population (fleet)

b = prey population (fish)

A = efficiency constant.

Further take the quadratic reproduction function

$$db/dt = \dot{b} = g(b) = Bb(\bar{b} - b) ,$$

where

$\dot{b}$ = the growth in fish population over time

$\bar{b}$ = maximum sustainable yield (MSY)

B = net reproductive efficiency constant.

Together with the productive capacity function, the growth in fish population over time becomes

$$\dot{b}\ (a,b) = Bb\ (\bar{b} - b) - Aab.$$

The control problem may then be stated:

$$\text{Maximize}\quad J\ (a,b,t) = \int_0^T (TR - TC)\ e^{-\rho t}\ dt,$$

where

TR = px = pAab

TC = wa

and

TR = total revenue

TC = total cost

p = market price of fish at the quay

w = market price of non-fish inputs (unit costs)

ρ = discount rate.

Subject to

a) The biological-technical constraint

$$\dot{b} = Bb\ (\bar{b} - b) - Aab,$$

b) The left hand transversality condition

$b(0) = b_o$ and

c) The right hand transversality condition

$$b(T) = b_T \quad \text{if} \quad T < \infty$$

$$\lim_{t\to\infty} e^{-\rho t} qb = 0 \quad \text{if} \quad T = \infty .$$

The present value ,(H), function in this case is

$$H = e^{-\rho t} \{(TR - TC) + q\dot{b}\} ,$$

where

q = the (shadow) price of fish left in the sea

which is the present value of the profits (TR - TC) plus the value $(q\dot{b})$ of the rate of investment in building up the current stock of fish.

The Pontryagin [3-5] necessary conditions for a maximization of the present value are

a) Maximize H with respect to a. Taking the partial derivative of H with respect to a and setting it equal to zero yields

$$q = (pAb - w)/Ab. \qquad (1)$$

b) Maximize H with respect to b. This yields

$$(p - q)\ Aa + \dot{q} = pq - B\ (\bar{b} - 2b)q. \qquad (2)$$

c) Fulfill the biological-technical constraint

$$\dot{b} = Bb\ (\bar{b} - b) - Aab\ . \qquad (3)$$

If an equilibrium exists, it will be where the value of a fish left in the sea is just equal the value of a fish taken out (i.e., $\dot{q} = \dot{b} = 0$). Set $\dot{q} = \dot{b} = 0$ in the equation (1), (2), (3) and solving yields

$$pB\ (\bar{b} - b^*)/(\rho + Bb^*) = (pAb^* - w)/Ab^* \qquad (6)$$

where

b^* = the equilibrium fish population

The equation (6) can then be solved to determine the optimal fish population, b^*. If the catch each year is set so that the population is maintained at level b^*, the greatest exploitation of the fishery over the long run can be achieved.

7.6 Generalization Results for Fisheries

This section contains a final integration of the components of this study. The Canadian results are generalized for the U.S. fishing operations and for world operations. All results are extended through the 1985-2000 time horizon. Benefits include only incremental improvements directly attributable to SEASAT. All 1974 dollar results are shifted to a 1975 dollar basis by using a 9 percent inflation rate, which is a weighted average of related price indices from the U.S. Department of Commerce, Survey of Current Business.

The benefits due to avoidance of adverse weather-related costs are taken from Sections 5.2 and 5.4. The failure to identify benefits in the area of direct tracking of fish populations and other production aspects is described above in Section 5.3. The technique by which SEASAT data may be utilized to improve fisheries population forecasts and thus fisheries management, is discussed in Sections 4.2 and 4.3.

The results of the Canadian study, after extending the results to include 1985-2000 discounted figures, are presented in Table 7.8. Using the survey of U.S. and World future fish

supply and demand in Sections 6.2 and 6.4, the Canadian results are extended to the U.S. (results in Table 7.8) and to the World (results in Table 7.10). The principal considerations in generalizing the results included: expected rates of growth of consumption, availability of various types of fish and prices of various types of fish. These data, which are presented in Sections 6.2 and 6.4, were used to construct growth paths of fish landings and weighted prices indices (since the relative costs of fish consumption varied from country to country quite substantially). The ratios of U.S. fish prices to Canadian fish prices and World fish prices to Canadian fish prices are presented in Tables 7.9 and 7.10, respectively. All results are then shifted to 1975 dollars and presented in Table 3.1, Summary of Overall Benefits, Marine Fisheries.

Table 7.8 Annual Canadian Benefits for Fisheries at a 1 percent to 4 percent Improvement in Operational Efficiency, 1985-2000

Year	Undiscounted, millions $ 1974				Discounted At 10%, millions $ 1974			
	Potential		Realistic		Potential		Realistic	
	Low	High	Low	High	Low	High	Low	High
1985	2.01	10.18	.66	2.87	.776	3.92	.25	1.10
1986	2.13	10.91	.84	3.81	.746	3.81	.29	1.33
1987	2.26	11.70	1.07	5.05	.716	3.70	.33	1.60
1988	2.40	12.54	1.36	6.70	.696	3.63	.39	1.94
1989	2.54	13.44	1.73	8.89	.668	3.53	.45	2.33
1990	2.70	14.40	2.20	11.80	.645	3.44	.52	2.82
1991	2.83	15.13	2.35	12.60	.617	3.29	.51	2.74
1992	2.96	15.90	2.51	13.50	.586	3.14	.49	2.67
1993	3.10	16.70	2.68	14.50	.558	3.00	.48	2.61
1994	3.25	17.55	2.87	15.50	.533	2.87	.47	2.54
1995	3.41	18.43	3.07	16.60	.508	2.74	.45	2.47
1996	3.57	19.37	3.28	17.80	.482	2.61	.44	2.40
1997	3.74	20.35	3.51	19.10	.460	2.50	.43	2.34
1998	3.92	21.40	3.76	20.50	.459	2.50	.43	2.39
1999	4.10	22.46	4.02	22.00	.418	2.29	.41	2.24
2000	4.30	23.60	4.30	22.60	.396	2.17	.39	2.17
Totals	49.22	264.06	40.21	213.82	9.264	49.14	6.73	35.69

References and Assumptions:

1. Potential and Realistic benefits for the years 1980, 1990 and 2000 were taken from The Canadian SEASAT Study. ECON has interpolated to derive the intermediate values.

2. The ranges of the potential benefits span the extremes of alternative assumptions; where - growth in industry doubling to tripling by year 2000.

Table 7.9 Annual United States Benefits for Fisheries at a 1 percent to 4 percent Improvement in Operational Efficiency, 1985-2000

Year	Canadian Landings, millions of lb.	U. S. Landings, millions of lb.	Realistic Undiscounted Canadian Benefits		Ratio of U. S. Price Per lb. to Canadian Price	Discounted U. S. Benefits, millions $ 1974	
			Low	High		Low	High
1985	2428	8007	.66	2.87	1.45	1.21	5.29
1986	2413	8025	.84	3.81	1.45	1.37	6.24
1987	2561	8097	1.07	5.05	1.45	1.55	7.33
1988	2630	8143	1.36	6.70	1.45	1.77	8.72
1989	2701	8189	1.73	8.89	1.45	2.00	10.27
1990	2774	8236	2.20	11.8	1.45	2.26	12.14
1991	2849	8282	2.35	12.6	1.45	2.15	11.57
1992	2926	8329	2.51	13.5	1.45	2.05	11.03
1993	3005	8379	2.68	14.5	1.45	1.94	10.54
1994	3086	8424	2.87	15.5	1.45	1.86	10.06
1995	3169	8471	3.07	16.6	1.45	1.77	9.58
1996	3255	8519	3.28	17.8	1.45	1.68	9.11
1997	3343	8567	3.51	19.1	1.45	1.60	8.72
1998	3433	8616	3.76	20.5	1.45	1.60	8.72
1999	3526	8664	4.02	22.0	1.45	1.46	7.99
2000	3622	8714	4.30	23.6	1.45	1.38	7.57
					Total Benefits	27.65	144.88

Assumptions:

1. 10 discount rate
2. Calculation: U.S. Landings/Canadian Landings X Price Ratio X Low or High Canadian Benefit = U.S. Low or High Benefit.

Table 7.10 Annual World Benefits for Fisheries at a 1 percent to 4 percent Improvement in Operational Efficiency, 1985-2000

Year	Canadian Landings, millions of lb.	World Landings, millions of lb.	Realistic Undiscounted Canadian Benefits		Ratio of World Price Per lb. to Canadian Price	Discounted World Benefits, millions $ 1974	
			Low	High		Low	High
1985	2428	171,156	.66	2.87	.618	11.09	48.26
1986	2493	171,993	.84	3.81	.618	12.53	56.85
1987	2561	172,834	1.07	5.05	.618	14.14	66.76
1988	2630	173,680	1.36	6.70	.618	16.09	79.29
1989	2701	174,529	1.73	8.89	.618	18.16	93.36
1990	2774	175,383	2.20	11.8	.618	20.54	110.19
1991	2849	176,241	2.35	12.6	.618	19.58	105.00
1992	2926	177,103	2.51	13.5	.618	18.58	99.98
1993	3005	177,970	2.68	14.5	.618	17.65	95.52
1994	3086	178,840	2.87	15.5	.618	16.85	91.04
1995	3169	179,715	3.07	16.6	.618	16.03	86.68
1996	3255	180,595	3.28	17.8	.618	15.18	82.39
1997	3343	181,478	3.51	19.1	.618	14.48	78.81
1998	3433	182,366	3.76	20.5	.618	14.44	78.74
1999	3526	183,258	4.02	22.0	.618	13.17	72.01
2000	3622	184,155	4.30	23.6	.618	12.43	68.22
					Total Benefits	250.9	1313.6

- applicable fisheries area; 50% in 1980 to 75% in 2000,
- range of improvement in operational efficncy 1% - 4%

3. 10% discount rate where discount factor equals 100 in 1975.

4. Realistic benefits account for learning and development factors, i.e., 10% of the potential benefits by 1980, 80% in 1990 and 100% in 2000.

REFERENCES

References: Chapter 4

4-1 Walsh, J. J. and R. C. Dugdale, "A Simulation of Nitrogen Flow in the Peruvian Upwelling Ecosystem," Investigacion Pesquera, 35:309-330, 1971.

4-2 Bakun, A., 1973, Coastal Upwelling Indices, West Coast of North America, 1946-71, NOAA Technical Report NMFS SSRF-671.

4-3 Curl, H. and L. F. Small, "Variations in Photosynthetic Assimilation Ratios in the Natural, Marine Phytoplankton Communities," Limnology and Oceanography, 10:R67-R73, 1965.

4-4 Steele, J. H., The Structure of Marine Ecosystems, Harvard University Press, 1974.

4-5 Walsh, J. J., A Spatial Simulation Model of the Peru Upwelling Ecosystem, Deep Sea Research, (In Press), 1975

4-6 Cushing, D. H., "Upwelling and Fish Production," FAO Fish. Tech. Paper, 84. 40p, 1969.

4-7 NOAA/NMFS, "Food Fish Market Review and Outlook," Current Economic Analysis F-19, Economic and Marketing Research Division. NOAA FFSOA-19, 1974.

4-8 Ryther, J. H. and C. S. Yentsch, "The Estimation of Phytoplankton Production in the Ocean from Chlorophyll and Light Data," Limnology and Oceanography, 2:281-286, 1957.

4-9 Smithsonian Meterological Tables, Sixth Revised Edition, Smithsonian Institution, Washington, D. C., 1966.

4-10 Background Paper No. 2, 1974, "Assessment Studies of Yellowfin Tuna in the Eastern Pacific Ocean," 30th Meeting, Inter-American Tropical Tuna Convention.

References: Chapter 6

6-1 Statistics Canada, Fisheries Stats of Canada, 24-201, 1972-3-4.

6-2 D. G. Wilder, "The American Lobster," Fisheries Fact Sheet Number 5, Fisheries and Marine Service Branch, Department of Environment, Ottawa, Nov., 1973.

6-3 Wilfred Templeton, Marine Resources of Newfoundland, Bulletin No. 154, Fisheries Research Board of Canada, Ottawa, 1966.

6-4 Philip A. Lapp, The Identification of Requirements Critical to Operations On and Below Ice Covered Waters, Ministry of State for Science and Technology, Ottawa, Sept., 1974.

6-5 A. H. Leim, W. B. Scott, Fishes of the Atlantic Coast of Canada, Bulletin No. 155, Fisheries Research Board of Canada, Ottawa, 1966.

References: Chapter 7

7-1 Volterra, V., "Theorie Mathématique de la Lutte Pour la Vie," Gauthier-Villars, Paris, 1931.

7-2 Schaefer, M.B., "Some Considerations of Population Dynamics and Economics in Relation to the Management of the Commercial Marine Fisheries," Journal of the Fisheries Research Board of Canada, 14 (5), September, 1957, pp. 669-81.

7-3 Crutchfield, James A. and A. Zellner, "Economic Aspects of the Pacific Halibut Fishery," in Fishery Industrial Research, 1 (1), Washington: U.S. Department of the Interior, 1962.

7-4 Food and Agricultural Organization, Economic Effects of Fishery Regulation, Fisheries Reports, No. 5, Rome, 1962.

7-5 Pontryagin, L. et al., The Mathematical Theory of Optimal Processes, Interscience: New York, 1962.

7-6 Christy, F.T. and A. Scott, The Common Wealth in Ocean Fisheries, Baltimore: Johns-Hopkins Press,

7-7 The Fisheries: Problems in Resource Management, edited by James A. Crutchfield, Seattle: University of Washington Press, 1965.

7-8 Smith, Vernon L., "Economics of Production from Natural Resources," American Economic Review, 58 (3), June 1968, pp. 409-31.

7-9 Smith, Vernon L., "On Models of Commercial Fishing," Journal of Political Economy, 77, 1969, pp. 181-98.

7-10 Shell, K., "Applications of Pontryagin's Maximum Principle to Economics," in Mathematical Systems Theory and Economics, edited by H.W. Kuhn and G.P. Szego, Springer: Berlin, 1969.

7-11 Edwards, R. and R. Hennemuth, "Maximum Yield: Assessment and Attainment," Oceanus, Vol. 18, No. 2, Winter 1975, pp. 3-9.

References: Chapter 7 (continued)

7-12 Robinson, M.A. and A. Crispoldi, "Trends in World Fisheries," Oceanus, Vol. 18, No. 2, Winter 1975, pp. 23-29.

7-13 Cheung, S.N.S., in Economics of Fisheries Management - A Symposium, University of British Columbia, Institute of Animal Resource Ecology, Vancouver, 1970.

7-14 Plourde, C.G., "A Simple Model of Replenishable Natural Resource Exploitation," American Economic Review, 60 (?), ? 1970, pp. 518-521.

7-15 Neher, Philip A., "Notes on the Volterra-Quadratic Fishery," Journal of Economic Theory, 8 (1), May 1974, pp. 39-49.

7-16 Beverton, R.J.H. and S.V. Holt, "On The Dynamics of Exploited Fish Populations," in Fisheries Investigation, 19 (2), London: Ministry of Agriculture, Fisheries, and Food, 1957.

7-17 Scott, A., "The Fishery: The Objectives of Sole Ownership," Journal of Political Economy, 63 (2), April 1955, pp. 116-24.

7-18 Gordon, H. Scott, "The Economic Theory of a Common-Property Resource: The Fishery," Journal of Political Economy, 62 (2), April 1954, pp. 124-42.

7-19 Lotka, A.J., Elements of Mathematical Biology, New York: Dover Publications, 1952.

7-20 Clark, C.W., "Profit Maximization and the Extinction of Animal Species," Journal of Political Economy, 81 (4), July-August 1973, pp. 950-961.

7-21 Turvey, Ralph, "Optimization in Fishery Regulation," American Economic Review, 54 (2), Part I, March 1964, pp. 64-76.

7-22 Quirk, J.P. and V.L. Smith, in Economics of Fisheries Management - A Symposium, University of British Columbia, Institute of Animal Resource Ecology, Vancouver, 1970.

References: Chapter 7 (continued)

7-23 Bell, Frederick W., et. al., "The Future of the World's Fishery Resources to the Year 2000." <u>Proceedings of the Marine Technology Society</u>, 1971.

7-24 Bardach, John E., et al., <u>The Status and Potential of Aquaculture</u>, Vol. II, Particularly Fish Culture. American Institute of Biological Sciences, Washington, D.C., May, 1968.

7-25 Committee on Commerce, <u>The Economic Value of Ocean Resources to the United States</u>, 93rd Congress, 2nd Section, Washington, D.C.: U.S. Government Printing Office, 1974.

7-26 Storer, J.A. and N. Bockstael, "LOS and the Fisheries," <u>Oceanus</u>, Vol. 18, No. 2, Winter 1975, pp. 42-47.